DTU Library

Using the IEA ETSAP modelling tools for Denmark

Grohnheit, Poul Erik

Publication date:
2008

Document Version
Publisher's PDF, also known as Version of record

Risø-R-Report

Risø DTU
National Laboratory
for Sustainable Energy

Using the IEA ETSAP modelling tools for Denmark

Poul Erik Grohnheit

Risø-R-1656(EN)

Risø National Laboratory for Sustainable Energy
Technical University of Denmark
Roskilde, Denmark
December 2008

Author: Poul Erik Grohnheit
Title: Using the IEA ETSAP modelling tools for Denmark
Department: Systems Analysis Department

Risø-R-1656(EN)
December 2008

Abstract (max. 2000 char.):
An important part of the cooperation within the IEA (International Energy Agency) is organised through national contributions to "Implementation Agreements" on energy technology and energy analyses. One of them is ETSAP (Energy Technology Systems Analysis Programme), started in 1976. Denmark has signed the agreement and contributed to some early annexes. This project is motivated by an invitation to participate in ETSAP Annex X, "Global Energy Systems and Common Analyses: Climate friendly, Secure and Productive Energy Systems" for the period 2005 to 2007. The main activity is semi-annual workshops focusing on presentations of model analyses and use of the ETSAP' tools (the MARKAL/TIMES family of models).

The project was also planned to benefit from the EU project "NEEDS - New Energy Externalities Developments for Sustainability. ETSAP is contributing to a part of NEEDS that develops the TIMES model for 29 European countries with assessment of future technologies. An additional project "Monitoring and Evaluation of the RES directives: implementation in EU27 and policy recommendations for 2020" (RES2020) under Intelligent Energy Europe was added, as well as the Danish "Centre for Energy, Environment and Health (CEEH), starting from January 2007.

This report summarises the activities under ETSAP Annex X and related project, emphasising the development of modelling tools that will be useful for modelling the Danish energy system. It is also a status report for the development of a model for Denmark, focusing on the tools and features that allow comparison with other countries and, particularly, to evaluate assumptions and results in international models covering Denmark.

ISSN 0106-2840
ISBN 978-87-550-3700-7

Contract no.:
33031-0141

Group's own reg. no.:
1200189

Sponsorship:
Danish Energy Research Programme 2005

Cover :

Pages: 76
Figures: 19
Tables: 25
References: 53

Information Service Department
Risø National Laboratory for Sustainable Energy
Technical University of Denmark
P.O.Box 49
DK-4000 Roskilde
Denmark
Telephone +45 46774004
bibl@risoe.dk
Fax +45 46774013
www.risoe.dtu.dk

Contents

Figures

Tables

Abbreviations

BAU	Business as usual
CCGT	combined cycle gas turbine
CCS	Carbon Capture and Storage
CEEH	Center for Energy, Environment and Health (Denmark)
CHP	combined heat and power
CO_2	carbon dioxide
DTU	Technical University of Denmark
EIA	Energy Information Administration (US)
EFOM	Energy Flow Optimisation Model
EFDA	European Fusion Development Agreement
EMF	Energy Modelling Forum (Stanford)
EPRI	Electric Power Research Institute
ETL	Endogenous Technology Learning
ETP	Energy Technology Perspectives (IEA)
ETSAP	Energy Technology Systems Analysis Programme
EU	European Union
GIS	geographical information systems
GW	Gigawatt
GWh	gigawatt hours
IEA	International Energy Agency
IER	Institut für Energiewirtschaft und Rationelle Energieanwendung, Universität Stuttgart
IEW	International Energy Workshop
IIASA	International Institute for Applied Systems Analysis (Laxenburg Austria)
IPCC	Intergovernmental Panel on Climate Change
kW	Kilowatt
kWh	kilowatt hours
MARKAL	Market Allocation (optimisation model developed by the IEA)
Mtoe	million ton of oil equivalent
MW	Megawatt
MWe	megawatt, electric
MWh	megawatt hours
NEEDS	New Energy Externalities Developments for Sustainability
NEET	Networks of Expertise in Energy Technology
Nord Pool	The Nordic Power Exchange
SAGE	System to Analyze Global Energy
SAPIENT	Systems Analysis for Progress and Innovation in Energy Technologies (EU),
TIAM	TIMES Integrated Assessment Model
TIMES	The Integrated Markal EFOM System
PJ	Petajoule 10^{15} Joule
RES	renewable energy sources
RFF	Resources for the Future
RTD	Research and Technology Development (EU Programmes)
SO_2	sulphur dioxide
TIMES	The Integrated Markal EFOM System
TJ	Terajoule 10^{12} Joule
toe	ton of oil equivalent
TWh	terawatt hours 10^{12} Wh
VEDA	VErsatile Data Analyst
USDoE	United States Department of Energy
VTT	Technical Research Centre of Finland
WEO	World Energy Outlook (IEA)

Preface

An important part of the cooperation within the IEA (International Energy Agency) is organised through national contributions to ”Implementation Agreements” on energy technology and energy analyses. One of them is ETSAP (Energy Technology Systems Analysis Programme), started in 1976. Denmark has signed the agreement and contributed to some early annexes.

This document is the final report of the project ”Danish participation in IEA-ETSAP, Annex X, 2005-2007” under the Danish Energy Research Programme 2005.

This project was motivated by an invitation to participate in ETSAP Annex X, "Global Energy Systems and Common Analyses: Climate friendly, Secure and Productive Energy Systems" for the period 2005 to 2007. The main activity is semi-annual workshops focusing on presentations of model analyses and use of the ETSAP' tools (the MARKAL/TIMES family of models).

The use of the ETSAP tools is linked to many other projects focusing on model application worldwide. This includes the organisations and institutions gathering in the annual International Energy Workshops (IEA), which are held back-to-back with one of the ETSAP semi-annual workshops. In recent years ETSAP has also contributed to European projects under the 6th Framework Programme and Intelligent Energy Europe.

The main activity of the project has been participation in the ETSAP workshops. The resources for preparation of contributions are limited. However, Danish contributions to these workshops should be part of the dissemination activity for Danish research projects. A key activity has the dissemination of ETSAP methods and results to the Danish Energy Agency and the Danish energy research community as well as Nordic and Baltic participants in ETSAP.

In particular ETSAP will contribute to the Centre for Energy, Environment and Health (CEEH), which is funded by the Danish Council for Strategic Research, and run over 5 years from January 2007.

A new project ”Danish participation in IEA-ETSAP, Annex XI, 2008-2010” was granted under the new Danish Energy Technology Development and Demonstration Programme 2008.

Risø DTU, December 2008

Poul Erik Grohnheit

1 Introduction

This report summarises the activities under ETSAP Annex X and related project, emphasising the development of modelling tools that will be useful for modelling the Danish energy system. It is also a status report for the development of a model for Denmark, focusing on the tools and features that allow comparison with other countries and, particularly, to evaluate assumptions and results in international models covering Denmark.

Thus, the aim is to describe the large amount of available information on the ETSAP modelling tools from a Danish national perspective.

Chapter 2 describes the history and development of ETSAP, and the current activities, emphasising the contents of the semi-annual workshops under Annex X, which has particular interest for development and use of energy models in Denmark. Selected presentations from these workshops are shown in tables.

Chapter 3 summarises the ongoing international studies using the ETSAP tools, in particular European studies with Danish participation (the European projects NEEDS and RES2020) and other studies which may be useful for current and future research and development projects in Denmark.

Chapter 4 describes the principles of the ETSAP tools, which belongs to the type of technology-rich 'bottom-up' flow optimisation energy models, emphasising the issues of data sources, user interface, model development and organisation, mathematical tools and key parameters. The stepwise development of national model within the framework of the NEEDS Pan-European models is described focusing on tools and activities for debugging and practical improvement of the models.

Chapter 5 describes the features of the Danish energy system, which are important for using the ETSAP model tools in the framework of the international model with emphasis on the Pan-European model that was developed under the NEEDS project.

Chapter 6 shows the results from the Reference Case for Denmark from the the Pan-European model released in October 2007 together with the aggregated scenario results for all 29 countries that were developed under the NEEDS project and reported at workshops within ETSAP and European or national research projects..

Finally, *Chapter 7* describes the current activities for use of the ETSAP tools within studies that are using the results of the tools developed under ETSAP Annex X and recommendations for further development of these tools

2 The IEA Implementation Agreement ETSAP

The Energy Technology Systems Analysis Programme (ETSAP) is an Implementing Agreement of the International Energy Agency (IEA), It was first established in 1976. The current agreement was revised in 2005.

2.1 IEA Implementing Agreements

ETSAP is one of some 40 Implementing Agreements. Most IAs are focusing on specific technologies, while a few are crosscutting focusing on the development and dissemination of technology data.

Table 2.1. IEA Implementing Agreements (IA) in recent years.

Information Centres, Systems Analysis, Cross-cutting (3-4 IAs)

- Energy Technology Systems Analysis Programme (ETSAP)
- Energy Technology Data Exchange/Information Centres
- Energy/Environmental/Climate Technologies

Energy End-Use (13-16 IAs)

- Transportation (4 IAs)
- Industry (2-5 IAs)
- Buildings (4-5 IAs),
- Demand-Side Management, Electricity Networks, District Heating and Cooling

Fossil Fuels (5-6 IAs)

Renewable Energy Technologies (9-10 IAs)

- Bioenergy
- Hydrogen
- Hydropower, Ocean Energy Systems
- Wind Energy, Solar (3 IAs), Geothermal,

Fusion Power(8-9 IAs)

A full list of IEA implementing Agreements is found at the IEA website under the topic Teccnology, *www.iea.org/Textbase/techno/ia.asp*, or together with related information on technology at *www.iea.org/Textbase/techno/index.asp*.

2.2 ETSAP's history

The activities of the Implementing Agreement is organised within annexes, normally running over three years. It is financed from national contributions to the annexes. Denmark signed the Implementing Agreement and took part in some early annexes, but has been inactive over some 20 years before participating in Annex X.

In 2005 the active participating countries were Australia, Belgium, Canada, EU, Finland, Germany, Greece, Italy, Japan, Korea, Norway, Sweden, Switzerland, Turkey, the Netherlands, United Kingdom and United States. Since 2005 France, Turkey and Denmark have joined and some countries have left or become inactive.

ETSAP is governed by the Executive Committee, which meets during the semi-annual workshop. The current Chair is Hertsel Labib, Natural Resources Canada, and the Operating Agent is GianCarlo Tosato, ASATREM srl,, Italy. The Desk Officer in the IEA Secretariat has been Fridtjof Unander, and from 2006 Peter Taylor.

"It functions as a consortium of member country teams and invited teams that actively cooperate to establish, maintain, and expand a consistent multi-country energy/-economy/environment/engineering (4E) analytical capability.

Its backbone consists of individual national teams in nearly 70 countries, and a common, comparable and combinable methodology, mainly based on the MARKAL / TIMES family of models, permitting the compilation of long term energy scenarios and in-depth national, multi-country, and global energy and environmental analyses."(www.etsap.org)

Table 2.2. ETSAP Annexes

	1976-77	Analysis of existing tools for evaluating R&D strategies
	1978-80	MARKAL Model generator development
Annex I	1981-83	Energy Technology Systems Analysis Project
Annex II	1984-86	Information Exchange Project
Annex III	1987-89	International Forum on Energy Environment Studies
Annex IV	1990-92	Greenhouse Gases And National Energy Options: Technologies & Costs for Reducing GHG Emissions
Annex V	1993-95	New Directions in energy modelling - *Top-Down/Bottom-Up*
Annex VI	1996-98	Dealing with uncertainty together - *Learning curves*
Annex VII	1999-02	Contributing to the Kyoto Protocol
Annex VIII	2002-05	Exploring Energy Technology Perspectives: Learning Strategies for Technological Development toward Sustainable Futures
Annex IX	2003-05	Energy Models Users' Group, 2003 -- *The MARKAL family of models*
Annex X	2005-07	Global Energy Systems and Common Analyses: Climate friendly, Secure and Productive Energy Systems,
Annex XI	2008-10	JOint STudies for New And Mitigated Energy Systems (JOSTNAMES): Climate friendly, Secure and Productive Energy Systems.

The focus of the early Annexes have been model development and technology descriptions. The focus shifted to environment – in particular emissions to the air from energy conversion and energy consumption. During the 1980s SO_2 and NO_x emissions was of primary interest, but from about 1990 nearly all the annexes have referred to Greenhouse Gasses. The focus of the Annexes during the last 15 years have been expansion of the classical model approach of energy flow optimisation modelling and combination with other approaches, e.g. macroeconomic 'top-down' modelling, technology learning and stochastic modelling. The key study object is climate change and technologies for mitigation

Working with models requires continuity and consistency. Many participants in the ETSAP community have long-long-term experience with this type of modelling. During the same time, key data for modelling have been institutionalised as official statistics, in particular data for energy flows and emission. Also capacity data for electricity generation is well described in the statistics, while other data for technologies are much less available.

2.3 ETSAP models

The MARKAL Family of models can be used for both global, national, regional and local optimisation of annual energy flows within a time horizon of some decades. All flows are annual, but the year can be divided into "time-slices" to reflect the systematic variations in demand for electricity and heat. In the classical MARKAL and the EFOM models these time slices were fixed to day-night or base-peak loads and two or three seasons.

Table 2.3. The MARKAL Family of Models (2002)

MARKAL – bottom-up LP model with perfect foresight
MARKAL-ED – elastic demand, partial equilibrium
MARKAL-ETL – endogenous technology learning
MARKAL-EV – calculation of environmental damage
MARKAL-GP – goal programming, "soft" constraints for pollutants
MARKAL-MACRO – link with a macroeconomic growth model
MARKAL-MACRO-MERGE – integration with a global trade model
MARKAL-MICRO – non-linear partial equilibrium approach
MARKAL-Stochastics – calculates hedging strategy
MATTER – MARKAL extension with materials flows
RMARKAL – Regionalised
Global RMM – RMARKAL with five world regions
SAGE – System to Analyse Global Energy – myopic MARKAL with stepped solutions (US DoE)
TIMES – The Integrated MARKAL EFOM System – greater flexibility

Source: ETSAP Newsletter, Vol. 7, No. 7, January 2002.

These models have been developed and run on different programming languages and computer platforms. Originally they were dependent on access to large university mainframes. From the beginning of the 1990s PC software became available for running MARKAL and EFOM. The General Algebraic Modeling System (GAMS) was first used for the link with a macroeconomic growth model, MACRO, but was later used for MARKAL itself. The development of the Integrated MARKAL EFOM System (TIMES) has used GAMS from the beginning of the development in 1996.

In addition to the extensions of the classical approach of overall optimisation mentioned in Table 2.1 a new approach using game theory to a regionalized global bottom-up model (Nash Equilibrium MARKAL) was developed and applied after 2002. (Annex VIII-IX report / Newsletter 8-6).

From about 2003 several model teams with long-term experience in EFOM or MARKAL have moved to TIMES or developed sectoral or regional models in TIMES, e.g. VTT, Finland, IER, Stuttgart, Germany and Politechnico di Torino, Italy, and a global model divided into 15 regions was initiated by the European Fusion Development Agreement (EFDA) on the basis of the SAGE model of the USDoE.

The largest coordinated effort for developing national models in TIMES has been the EU-wide TIMES modelling project NEEDS within the Sixth Framework Program of the

In parallel with this effort TIMES has been expanded gradually to include most of the features of the MARKAL family of models.

While MARKAL is still used by several users – mainly national teams with long modelling experience – TIMES is now becoming the basis for several new international collaborative projects.

Table 2.4. ETSAP semi annual workshops since 2002

Annex	Time and location	ETSAP Topic	Joint workshop
VIII	Torino, Italy, October 2002		
VIII	Vienna, Austria, June 2003	Workshop	ETSAP – EMF – IEA - IIASA. International Energy Workshop
VIII	Beijing, China, October 2003	Workshop	IEA Seminar on Energy Modelling and Statistics
VIII	Paris, France, June 2004	Workshop	EMF/IEA/IIASA/ETSAP
VIII	Firenze, Italy, November, 2004		EU-NEEDS (New Energy Externalities Developments for Sustainability). Kick-off meeting of Research Stream 2a: “Energy systems modelling and internalisation strategies, including scenarios building”
IX	Taipei, Taiwan, April 2005		Technical Conference of Energy Models Users’ Group: Global and Regional Energy Modelling
X	Kyoto, Japan, July 2005	ETSAP tools update	Annual Meeting of the International Energy Workshop 2005, Jointly organized by RITE, CRIEPI, EPRI, IEEJ, JSER, NEDO, EMF, IEA(ETSAP) and IIASA
X	Oxford, UK, November 2005	Models and studies	Oxford, November 2005 with Workshop on Modelling Future Energy Technology Cost and Technology Choice, organised by UKERC, in collaboration with ETSAP, PSI, DTI and AEAT
X	Cape Town,South Africa, June 2006	IEA G8 Plan of Work in response to the Gleneagles Communiqué	25th International Energy Workshop, organized by IIASA, EMF (Stanford), the IEA and the Energy Research Centre of the University of Cape Town.
X	Stuttgart, Germany, November 2006	Training on VEDA-TIMES, TIMES integrated assessment model (TIAM)	jointly with NEEDS. Development of national and global models using the TIMES model and the interface VEDA.
X	Stanford, California, June 2007	Models and studies	Annual Meeting of the International Energy Workshop 2007, EMF, IEA, and RFF
X	Brasilia, Brazil, November 2007	Introduction to IEA/ETSAP tools for energy systems analyses	Brazil – IEA/NEET Workshop
XI	Paris, France, June 2008		Annual Meeting of the International Energy Workshop 2008 EMF, IEA, and RFF

2.4 The IEA G8 Plan of Action

An important part of the activities under Annex X has been contributions to the IEA: G8 Gleneagles Programme ”Aiming at a clean, clever and competitive energy future”. This programme was initiated at the G8 Summit in Scotland in July 2005 and at the July 2008 G8 Summit in Hokkaido/Toyako (Japan), IEA submitted reports and findings from its three years of work for the G8.

Table 2.5. Selected presentations from the IEW-ETSAP workshop in Cape Town, June 2006.

Global models
Global Energy Supply: Model-based Scenario Analysis of Resource Use and Energy Trade. *Uwe Remme, Maryse Labriet, Richard Loulou, Markus Blesl, Stuttgart and Montreal*
Emission Trade
A EU-Italy Model to Evaluate the National Plans for the EU-Emission Trading Scheme. *Umberto Ciorba, Francesco Gracceva, Giancarlo Tosato. ENEA, Rome*
Macro-economic modelling approaches
A European Model on Municipal Waste. *Alejandro Villanueva, Mette Skovgaard, Marko Vrgoc, Frits Møller Andersen, Helge V. Larsen, Stéphane Isoard, European Topic Centre on Resource and Waste Management, Risø, European Environment Agency*
Electricity Sector
The Italian Electricity Sector: A Regional and Multi Grid TIMES Model. *Maurizio Gargiulo, Evasio Lavagno, Cristina Cavicchioli, Santi Vitale, Torino and Milano*.
Technology learning
Endogenised Technological Progress in TIMES Models. *Martin Baumann, Graz Austria.*
Wind
Wind Energy: A Challenge for Energy Models. *Thomas Hamacher, Nina Heitmann, Joachim Herrmann, Stephan Braun, Garching, Augsburg and Greifswald, Germany.*

Table 2.6. Selected presentations from the NEEDS-ETSAP workshop, Stuttgart, November 2006.

NEEDS
The NEEDS TIMES Pan-European model, *Markus Blesl, Institut für Energiewirtschaft und RationelleEnergieanwendung, Universität Stuttgart*
VEDA
The VErsatile Data Analyst (VEDA), *Amit Kanudia, Gary A. Goldstein*
TIAM
Genesis of TIAM (TIMES Integrated Assessment Model), *Richard Loulou*.
Structure of the TIMES Integrated Assessment Model (TIAM), *Maryse Labriet*.
Analysis of climate policies under uncertainty with TIAM and the new Climate Module, *Richard Loulou, Maryse Labriet, Amit Kanudia.*
Modeling of fossil resources and trade in the TIAM model - Results of the base scenario, *Uwe Remme, Maryse Labriet, Richard Loulou, Markus Blesl*
Myopic TIMES version: Concept and first results, *Uwe Remme, Markus Blesl*

The IEA G8 Plan of Action has led to a major expansion of the IEA activities on modelling including an expansion in the staff in the Secretariat. A series of workshops was held during 2006, and a Networks of Expertise in Energy Technology (NEET) was launched in May 2006.

Major target countries for the NEET network has been the 'plus 5' countries (Brazil, China, India, Mexico and South Africa). ETSAP has already been actively engaged with key institutions in the +5 for more than a decade.

Table 2.7. Selected presentations from the IEW-ETSAP workshop at Stanford, June 2007.

Stanford: TIMES applications – NEEDS and RES2020 Consortia
Possible Time-consistent Participation Schemes for Post-2012 Climate Policy. *Juan Carlos Ciscar, Antonio Soria and Denise Van Regemorter.*
Desperately Seeking for Energy Efficiency… Using Information and Communication Technologies? *Vincent Mazauric, Nadia Maïzi, Alain Anglade and Gilles Guerassimoff.*
Future Energy Scenarios in Spain Given the European Energy and Climate Policy Framework. *Maryse Labriet, Helena Cabal, Natalia Caldès, and Yolanda Lechón.*
Electricity Technology Perspectives for a Sustainable Electricity Supply in Europe. *Alfred Voß, Ingo Ellersdorfer, Markus Blesl, and Ulrich Fahl.*
Hydrogen and Biofuels as Competing Energy Carriers in Western Europe. *Timur Gül, Leonardo Barreto, and Socrates Kypreos.*
Impact of Capital Rationing on the Adoption of Climate-friendly Energy Technologies in a Developing Countries Framework. *Richard Loulou, Maryse Labriet, Amit Kanudia, Alain Haurie, Giancarlo Tosato.*
Electricity Trading in Europe under Different Emission Trading Schemes. *Markus Blesl.*
Assessing the Effects of the European Emissions Trading Scheme for Portugal Using the TIMES_PT Model. *Sofia Simões, João Cleto and Júlia Seixas.*
On the Cost Effectiveness of Biomass Gasification in the District Heating Systems of Västra Götaland, Sweden – A MARKAL Modelling Analysis. *Martin Börjesson and Erik O. Ahlgren.*
The NEEDS TIMES Model: Italy and Slovenia Case Studies. *C. Cosmi, S. Di Leo, S. Loperte, M. Macchiato, F. Pietrapertosa, M. Salvia, and V. Cuomo.*
Prospective Analysis of the Chilean Power Generation Park with MARKAL. *Felipe Pichard, Edi Assoumou, Gilles Guerassimoff, Nadia Maïzi, Marc Bordier.*
Semi-annual ETSAP Regular Workshop ETSAP Semi-annual Regular Workshop
Insight from the Pan-EU TIMES model of NEEDS. *Markus Blesl, Uwe Remme, IER, Stuttgart University,*
A reduced version of the Pan-EU TIMES model of NEEDS, *Amit Kanudia, Richard Loulou, Maurizio Gargiulo, GianCarlo Tosato.*
Methodology and preliminary results
Using data from ETSAP models in a hemispheric pollution model, *Marie-Louise Siggaard-Andersen, Kenneth Karlsson, Poul Erik Grohnheit.*

The most prominent outcome of the work has been two large reports in 2006 and 2008 on *Energy Technology Perspectives: Scenarios & Strategies to 2050*, aiming at d*emonstrate* how energy technologies can make a difference in global scenarios to 2050.

The origin of ETP dates back to ETSAP Activities from 2001 – to be used in WEO 2002 (Newsletter Vol. 7 No. 6 October 2001) "WEO 2000 investigated the impact of new technologies more closely than previous IEA projections. The Energy Technology Perspectives project will take an even more detailed view of technology development, focusing on the long term. The project will collect and assess state-of the-art technology information, drawing on relevant IEA projects with Implementing Agreements. The information collected will include estimates of 'technology learning effects', that is, cost reduction as the cumulative production of a technology increases."

Table 2.8. Selected presentations from the Brazil-NEET-ETSAP Workshop in Brasilia, November 2007.

Brazil – IEA/NEET Workshop
Introduction to ETSAP and the MARKAL-TIMES models generators, *GianCarlo Tosato.*
Hands-on session to build a first draft TIMES-Brazil model.
VEDA
The VErsatile Data Analyst (VEDA), *Amit Kanudia, Gary A. Goldstein.*
TIAM
The TIMES Integrated Assessment Model (TIAM): An Introduction, *Richard Loulou, Maryse Labriet, Amit Kanudia, Uwe Remme, Antti Lettilä.*
ETSAP-TIAM recalibration and recent improvements, *A. Kanudia, M. Labriet, R. Loulou, U. Remme.*
Using ETSAP-TIAM for national policy analyses: the "country-out-region-in" Procedure, *Amit Kanudia*.
EU Projects
The EC project RES2020: an update, *Maurizio Gargiulo, et al.*
Secure energy corridors for Europe: the EC REACCESS project, *Evasio Lavagno.*
G8 plus 5
TIMES China Model 34 Regions (TCM34R), *Gargiulo M., De Miglio R., Li X., Wang Y.*
Towards a new Russia TIMES Model, *Oleg Lugovoy*.

2.5 ETSAP workshops

The semi-annual workshops are open for participation and contributions from modelelers throughout the world. Normally they are 2-days events that are held back-to-back with the annual International Energy Workshops (IEW) or meetings of national modelling communities or project meeting within international modelling projects, in particular European projects under the 6th Framework Programme and Intelligent Energy Europe.

The aim of these workshops is to discuss methodologies, disseminate results, and provide opportunities for new users to get acquainted with advanced energy-technologies, systems and modelling developments. Table 2.4 summarises the topics of the workshops since 2002 under the Annexes VIII, IX and X.

The first workshop jointly with the NEEDS Project, Research Stream 2a: "Energy systems modelling and internalisation strategies, including scenarios building" was in November 2004 under ETSAP Annex VIII, when the Kick-off meeting was held in Firenze, Italy. This workshop was followed up two years later in Stuttgart, when harmonised TIMES models for 29 European countries were being tested and a Pan-European model was under preparation.

The meeting in November 2005 were held jointly the UK Energy Research Centre was established in 2004 as the focal point for UK research on sustainable energy. The Centre is organised into themes and functions which are run from seven university institutions in England and Scotland.

The meetings in June 2006 and November 2007 were held in two of the ‘plus 5’ countries, South Africa and Brazil. South Africa had been active users of the ETSAP modelling tools for some years, while Brazil was a newcomer.

The meeting in Cape Town, South Africa followed the tradition of workshops jointly with the International Energy Workshop (IEW) similar to the meetings in June 2005, 2007 and 2008. Table 2.5 shows examples of papers of selected modelling topics from the IEW workshop in Cape Town (global, models, modelling of emission trade, a macroeconomic modelling approach used for municipal waste, regional electricity modelling, and wind energy in energy models). Table 2.6 shows selected presentations of various features of TIMES model from the regular ETSAP workshop in Stuttgart, November 2006. Table 2.7 shows a number of presentations from the IEW workshop at Stanford, June 2007 on TIMES applications from the NEEDS and RES2020 consortia. Some of these presentations were followed up at the next IEW workshop in Paris, July 2008 as seen in Table 2.9.

Detailed information of the workshops and the ETSAP tools are found on the ETSAP website *www.etsap.org*.

2.6 Annex X Final Report

The report “Global Energy Systems” and Common Analyses was presented at the workshop in Paris, July 2008. It consists of two volumes “Highlights and Summary” and the full report. The report illustrates fifty or more models, studies and analyses carried out with ETSAP tools. In the presentation two global model development undertakings are particularly emphasised as they have brought the state-of-the-art for comprehensive energy system analysis to new heights. These are the global applications associated with the publication of the IEA Energy Technology Perspective (ETP) in 2006 and 2008, and the assessment of possible routes to climate stabilization using ETSAP TIMES Integrated Assessment Model (TIAM).

There are six projects using multi-regional models, EC-NEEDS) Project, Studies with the EU30 TIMES-Electricity and Gas supply model, the South East Europe Regional Energy Market Support (SEE REMS) Project, and three collaborative studies covering regions in Asia, including India and China.

Activities by ETSAP partners and other users of ETSAP tools are summarised. These activities are mainly national model studies, focusing on national energy environmental policies using both MARKAL and TIMES.

Finally, there are Appendices containing official documents, Workshop agendas and surveys of the ETSAP Tools.

2.7 Programme for ETSAP Annex XI

The next Annex XI runs from 2008 to 2010. The title of the Annex is “JOint STudies for New And Mitigated Energy Systems (JOSTNAMES)” with the subtitle “Climate friendly, Secure and Productive Energy Systems”.

The programme for the Annex was adopted on the ETSAP Executive Committee Meeting in November 2007. There are four main objectives:

Table 2.9. Selected presentations from the IEW-ETSAP workshop in Paris, June-July 2008.

IEW Stanford to Paris: TIMES applications by European Consortia

Insight in energy technologies prospects given the EU climate and energy policy, an analysis with the PET, the Pan-European TIMES model. *M. Gargiulo, A. Kanudia, D. Van Regemorter.*

Climate change, energy security and prospective energy scenarios in Spain. *Maryse Labriet, Helena Cabal, and Yolanda Lechón.*

The role of technologies and structural changes in the energy system of the EU 27 to achieve the 440 ppm target. *Markus Blesl, Tom Kober, David Bruchof.*

Uncertainty and Discounting in the Monte-Carlo Version of MERGE. *Socrates Kypreos and Bertrand Magnè.*

Contribution of the large developing countries to the global climate mitigation: potential for technology options. *Laurent Drouet, Amit Kanudia, Maryse Labriet, Richard Loulou, Marc Viell.*

Impact of CCS deployment on wholesale electricity prices in North-Western Europe. *Ad Seebregts, Heleen Groenenberg.*

The Cost of Counteracting Policy Instruments: The case of feed-in-tariffs, CO2 emission trading and on-budget aids to natural gas. *Sofia Simões, João Cleto, Júlia Seixas, Patrícia Fortes.*

Economic consequences of climate change in Europe. *J. C. Ciscar, Denise van Regemorter, L. Szabo.*

Regional energy planning: a case study. *Rocco De Miglio, Maurizio Gargiulo, Evasio Lavagno.*

Global transportation scenarios in the multi regional EFDA-TIMES energy model. *Pascal Muehlich, Thomas Hamacher, Tobias Hartmann.*

Internalizing Externalities of both Heat production and Electricity generation in TIMES-Sweden – What difference does it make? *Anna Krook Riekkola and Erik O. Ahlgren.*

IEW Paris: Contributions on Waste and biomass, etc. Use of GIS

Biofuels Production and Trade under the U.S. Energy Independence and Security Act of 2007. *Audrey Lee, Thomas Alfstad, and Bhima Sastri.*

Evaluation of Biomass-derived Transport Fuels in Germany. *Carolin Funk, Dag Martinsen, Jochen Linßen.*

Energy models for urban planning: the slow track to more energy efficiency and greenhouse gas emission reductions. *T. Hamacher, J. Herrmann, F. Botzenhart, P. Mühlich, P. Böhme.*

Sustainable Renewable Energy Mix for Europe – a GIS-based high-resolution inventory and optimization model. *Yvonne Scholz, Wolfram Krewitt.*

GIS-based Model to Optimize Possible Self-sustaining Regions in the Context of a Renewable Energy Supply. *Markus Biberacher, Sabine Gadocha.*

Energy optimization in Waste treatment. *S. V. Srinivasan, E. Ravindranath, R. Sunthanthararajan,K. Sri Balakameshwari, K. Thirumaran, K. Chitra, B. Umamaheswari.*

Waste-to-energy technologies in TIMES models. *Poul Erik Grohnheit, Kenneth Karlsson, and Marie Münster.*

– Research and Development focusing on advancing the state-of-the-art with respect to energy systems analyses and integrated energy / economic / environmental /engineering modelling.

– Co-ordinated Analyses using the methodologies for global and/or regional energy systems studies

– Capacity building aiming at maintaining and improving capabilities for energy systems analyses and the use of ETSAP tools.

– Tools maintenance as the minimum objective of this Annex to maintain and update ETSAP model generators (MARKAL, TIMES) and users' interfaces (ANSWER, VEDA), and to organize two semi-annual workshops every year.

The budget will depend on the number of national contributions with the annual fee 20,000 € of the first year and not more in the following years.

The detailed work programme for 2008 that were adopted at the following Executive Committee meeting in July 2008 focused on the development of a common technology database, further development of the ETSAP-TIAM model and support to ETSAP tools users in the form of tutorial models, improved documentation of the tools and training of new and experienced users. During the autumn of 2008 three courses are scheduled in Astana, Kazakhstan, London, UK, and Nice, France in December – back-to-back with the semi-annual workshop.

3 International studies using the ETSAP tools

This chapter summarises the ongoing international studies using the ETSAP tools, in particular European studies with Danish participation (the European projects NEEDS and RES2020) and other studies which may be useful for current and future research and development projects in Denmark.

3.1 The EU NEEDS project

The NEEDS (New Energy Externalities Developments for Sustainability) is an I*ntegrated* Project under the EU 6th Framework Programme. It addresses Priority 6.1: Sustainable Energy Systems and, more specifically, Sub-priority 6.1.3.2.5: Socio-economic tools and concepts for energy strategy.

The NEEDS consortium includes 66 partners from 26 countries. It presents a balanced mix of universities, research institutions, industry and NGOs. The overall coordinator is ISIS – Institute of Studies for the Integration of Systems, Rome.

The ultimate objective of NEEDS is to evaluate the full costs and benefits (i.e. direct + external) of energy policies and of future energy systems, both at the level of individual countries and for the enlarged EU as a whole. Major advancements will be achieved in the three main areas of:

- Life Cycle Assessment (LCA) of energy technologies
- monetary valuation of externalities from energy production, transport, conversion and use
- integration of LCA and externalities information into policy formulation and scenario building.

The NEEDS project is probably one of the largest international projects on systems analysis. It was started in September 2004 and was originally scheduled for four years, which has now been extended by six months, so the project will end in spring 2009.

3.1.1 NEEDS Research Stream 2a on modelling

The project is organised into nine Research Streams, covering the topics of the three main areas, development of methods and data, and dissemination and communication of results.

The Research Stream 2a "Modelling internalisation strategies, including scenario building" aims at generating a partial equilibrium technology-rich economic models of EU25, accession countries plus Norway and Switzerland, and of the EU as a whole (now known as the Pan-European TIMES Model) including the most important emissions, materials, and damage functions used by LCA and ExternE.

RS2a includes 14 partners from EU27 and the consultant on the development of the TIMES model. Each of the European partners is responsible for one or more of the national NEEDS-TIMES models. Most of these partners have been active in the ETSAP community for many years.

The programme for this research stream was developed in close cooperation with the ETSAP community under Annex VIII, and the key modelling tool has been the TIMES model with the VEDA user interface.

A long-term time horizon (2050, by 5-year step) is used to support the definition of long term strategies, taking into account different standards of energy devices and technologies development.

3.1.2 NEEDS-TIMES model

The first main deliverable from NEEDS of interest for the further development of NEEDS-TIMES is “Technology repository SubRES (RS2a)”. This is a database that includes all techno-economic and environmental data for reference technologies to be used for the optimisation model. It covers both current and future technology vintages divided into the sectors:

- Supply (upstream technologies)
- Electricity and heat generation
- Industry
- Residential, Commercial and Agriculture
- Transport

For a full description of this database, please refer to: RS2a_T2.7: Reference technology database.

By the end of ETSAP Annex X the first scenario results of the Pan-European model had been presented, and a running harmonised national model in NEEDS-TIMES was available for 30 European countries (now EU27 plus Norway, Iceland and Switzerland).

The further development and application of the Pan-European model will now take place under other projects, in particular the RES2020 Project under the EU programme Intelligent Energy Europe.

NEEDS was started in September 2004. It was originally scheduled for four years, but was extended by 6 months, so the project will end by February 2009.

NEEDS results – in particular the technology repository and the Pan-European model is used in other EU financed projects, in particular RES2020 (see below) and REACCESS (Risk of Energy Availability: Common Corridors for Europe Supply Security) – started in February 2008. Participation from Italy, Kazakhstan, Spain, Germany, France, Russia, Norway, Greece, Austria and Finland. Focusing on energy import to the EU, security of supply and environmental policies.

3.1.3 NEEDS intellectual property rights

In a document presenting a general framework for the effective and integrated exploitation of the NEEDS findings it is stated that the project is intended to provide direct, usable inputs to the formulation and evaluation of energy policies in the overall framework of sustainability. Details of how to fulfil this ambition is described in the document "Guidelines to Policy Use of NEEDS results”, http://www.needs-project.org/docs/Policy%20Guidelines.pdf.

A final version of these Guidelines will be issued towards the end of the project life, covering all aspects currently provisional or/and incomplete.

3.2 The EU RES2020 project

The project “Monitoring and Evaluation of the RES directives implementation in EU27 and policy recommendations for 2020 – RES2020” is supported by the EU programme

Intelligent Energy Europe. The consortium consists of 14 partners from 12 countries within EU27. Most of the partners took part in NEEDS RS2a. A key additional partner is the European Renewable Energy Council – EREC. The project is coordinated by Center for Renewable Energy Source – CRES, Greece. The project was started in October 2006 and will finish by March 2009. The EU funding is 0.6 M€.

RES2020 aims at analysing the present situation in the RES implementation, defining future options for policies and measures, calculating concrete targets for the RES contribution that can be achieved by the implementation of these options and finally examining the implications of the achievement of these targets to the European economy.

A number of future options for policies and measures will be defined and they will be studied with the use of the TIMES energy systems analysis model, in order to analyze the quantitative effects on the RES development. The results will be combined to provide recommendations of optimal mix scenarios for policy measures, in order to ensure the achievement of the targets.

The first major results of the project are comprehensive RES Policy Reviews for each of the EU 27 Member States, which have been drafted by EREC, who is the umbrella organisation of the European renewable energy industry and research associations The Policy Reviews describe the existing RES situation in each EU27 Member State (in terms of share of RES in the total primary energy consumption and share of RES in the gross final energy consumption), the mandatory targets set by the newly proposed RES Framework Directive from 2008 are explained as well as the indicative target set by the RES-electricity European Directive from 2001 and indicative target set by the European Biofuels Directive from 2003. The policy reviews are live documents and will be continuously updated. The reviews can be downloaded from the EREC website (www.erec.org).

The NEEDS-TIMES Pan-European model has been enhanced for the renewable technologies that are in the focus of the RES2020 project. These are

- Renewable electricity generation, including wind and distributed electricity generation
- Biomass for electricity and heat

In the original project plan it was assumed that the NEEDS-TIMES model should be run with the enhancements country by country by the model teams. This has been changed, so that the Pan-European model, which has been taken over from NEEDS will be run centrally as a multi-regional model. This means that both enhancements and calibration of 2005 data from Eurostat have been made centrally, and the first set of results from each country, which were run by the new Version 4 of the VEDA Front End software, were distributed to the teams responsible for the national models were distributed by June 2008.

Following this release the RES2020 Pan-European TIMES model is being further developed centrally with co-ordination of the assumptions with those of the recent studies using the PRIMES model, which has been the key tool for energy end environment forecasts by the European Commission over the last decade.

3.3 The European TIMES-EG model

The European Electricity and Gas Supply model TIMES-EG uses the TIMES model generator to illustrate in detail the electricity supply industry of the member states of the EU 30 for the period from 2000 to 2030. The different basic conditions of the countries are described by country-specific parameters such as fuel prices, data for the potential of renewable energy sources and region characteristic load curves for different customer groups (residential, commercial, energy-intensive and energy-extensive industry, traffic). In addition to the energy flows also the energy-related greenhouse gas emissions are modelled. Thus, the model allows to analyse the opportunities of an emission trading scheme.

When assuming a complete competition within the European electricity market the total costs for the entire investigated region are to be minimised. This leads to an electricity exchange within the system whenever the difference of the marginal load costs of a certain load segment at a certain time between regions is larger than the total costs for transmission and transmission losses. The limiting factors for interregional electricity exchange are the maximum interconnection capacities. Besides existing transfer capacities TIMES-EG includes major planned electricity grid extensions between the European countries.

Two analyses using the TIMES-EG model are referred in the ETSAP Annex X report "The Role of Combined Heat and Power and District Heat in Europe" and "Role of Technology Progress on Investment Decisions in the European Electricity Market". In addition to these two analyses, the TIMES-EG model has been used in various studies to assess future challenges in the European electricity and gas sector, for example in the EU-EUSUSTEL project, in which the results from the TIMES-EG model were confronted with results from the PRIMES model, using the assumptions from each of the models.

The results from the two models are substantially the same, in particular concerning electricity generation technologies. The main difference is that the split between coal and gas is more sensitive to parameter variations in TIMES. This is explained by the more straightforward optimisation in TIMES compared to PRIMES. The cost of electricity generation is systematically lower in TIMES than in PRIMES, in particular in the starting year, but decreasing during the optimisation period. This is also explained by the structure and calibration of the models. PRIMES has been calibrated to represent the European energy markets over more than ten years and used in many studies. The version of the TIMES-EG model used for EUSUSTEL is using a dataset that is specific for the study, and the results on electricity prices are in dual values from the linear programming optimisation. In spite of the weaknesses mentioned above, the conclusion is that both sets of model results represent the state-of -the-art for scenario models available for the European electricity market. The report defines the potential network challenges that arise under the different scenarios of the EUSUSTEL project. Scenarios that are especially demanding for the transmission grid are scenarios with a lot of renewables (which will largely be wind) and scenarios that rely on import to secure supply. Scenarios that are especially demanding for the distribution grid are scenarios with distributed generation and demand response programs to manage demand with real time metering and balancing.

3.4 The global TIAM model

The ETSAP-TIAM (TIMES Integrated Assessment Model) is a detailed, technology-rich global TIMES model. The structure and data came from the MARKAL-based SAGE model that was developed by the US Dept of Energy's Energy Information Administration (www.eia.doe.gov). SAGE is also the origin for the VEDA database user interface, which is now used for NEEDS and RES2020 TIMES.

The world is divided into 15 regions as shown in Table 3.1. The time horizon is 2100, which is needed for long-term climate mitigation policies.

The main structure of the energy system is similar to the structure of the NEEDS-TIMES model, but with less emphasis on the technological details in the downstream sectors (transport, industry, residential, commercial and agriculture) and more focus on the energy resources in the Upstream sector (Supply sector in NEEDS-TIMES), in which the global regions are divided into OPEC and non-OPEC countries.

The results of ETSAP-TIAM studies have wide diffusion among the groups that assess climate mitigation policies through EMF and IPCC.

In the summary of the ETSAP Annex X report an analysis examining Hedging Strategies for Climate Stablilization is presented to illustrate the application of the model. This is one of the aspects of the climate change studies of The Energy Modeling Forum (EMF). EMF is a long standing international forum based at Stanford University, which brings together the leading global energy modellers to look at the pressing energy and environmental issues.

Six long range temperature change targets from 2.1 to 3.3°C were analyzed [Reference increase 4.6°C; smallest achievable increase 1.9°C at very high cost.] Targets 2.1°C and 2.3°C are difficult and very expensive to attain, while 3.3°C is quite easy.

Table 3.1. 15 regions in the global models SAGE, EFDA and TIAM

AFR	Africa	JPN	Japan
AUS	Australia-New Zealand	MEX	Mexico
CAN	Canada	MEA	Middle-East
CSA	Central and South America	OAS	Rest of Asia
CHI	China	SKO	South Korea
EEU	Eastern Europe	USA	United States
FSU	Former Soviet Union	WEU	Western Europe
IND	India		

The development of TIAM and climate change studies were important topics for presentations at the ETSAP semi-annual workshops and the joint workshops with the International Energy Workshop under ETSAP Annex X.

The further development of TIAM is a key task of the ETSAP Annex XI programme. This includes an effort for improving the extraction-recalibration facilities of countries in ETSAP-TIAM. So far a national model (Italy) extracted from ETSAP-TIAM has been tested and the process of completing the recalibration with the existing MARKAL-Italy model is underway. The procedure and the difficulties were presented in the last session of the ETSAP workshop in Paris July 2008. The experience suggested devoting additional resources in order to improve the procedure.

A similar national model has been provided for Denmark. However, much work needs to be done, before this model may be used for scenario studies.

3.5 The EFDA-TIMES model on fusion energy

As a part of the research under the European Fusion Development Agreement (EFDA) there is a small programme on Socio-Economic Research on Fusion (SERF). The analyses within this programme goes beyond the “levelised cost” methodology, which is used for example in OECD and IAEA studies for comparison of technologies for base-load electricity generation. In the first series of SERF studies the levelised cost were estimated between 50 and 100 Euro-1995 per MWh. Such prediction of the absolute cost of fusion-generated electricity in more than 50 years from now requires in particular a realistic assessment of the uncertainties. A large number of calculations were therefore carried out, covering ranges of assumptions for the key physics and technology parameters affecting the economic performance of a power plant (Borelli et al., 2001).

The levelised cost method does not address the issue of whether, and under what conditions fusion could capture a share of the European energy market. This issue was examined by including fusion into the widely used MARKAL model, which simulates decisions to invest in and utilise energy technologies.

The MARKAL studies showed that the market role of fusion in Western Europe century would strongly depend on the implementation of pollution reduction policies. In the unconstrained scenarios, fusion and renewables could not compete effectively with coal. The energy system changes profoundly if CO_2 constraints are imposed. Introducing CO_2 – stabilisation targets into the calculations in the form of total emission budgets for the time period up to 2100. For target concentrations between 550-450 ppm the installed fusion power reaches an imposed growth limit corresponding to 160 GW installed power in 2100. Renewables and fusion power grow approximately in parallel, with little direct competition between them due to their different role as intermittent and base-load power sources. These results seemed robust with respect to the broad range of variations in the assumptions made in the calculations.

The first version of the EFDA-TIMES Modelling Framework was developed for EFDA by an external consortium of experts and delivered in autumn 2004.

The motivation for this development was that fusion power practically not considered in existing long-term energy scenarios (e.g. IIASA-WEC, IPCC SRES) and that the earlier energy scenario studies within EFDA only considered Western Europe or used a basic single-region global model.

The structure and data of the first EFDA-TIMES model were similar to the SAGE and TIAM models and the further development has benefited on the synergy with the development of the VEDA user interface software , which were improved significantly as a part of the NEEDS project.

The further development and use of the EFDA-TIMES model as an important part of the SERF programme will continue during the coming years under the EU 7th Frame Programme (EFDA 2008). The EFDA work programme for 2008 and 2009 consider a validation and benchmarking phase for EFDA-TIMES and a joint contribution to an international energy modelling conference (e.g. IEW); presentation at the semi-annual ETSAP meeting of the IEA on the status and progress of the model by Mid-2009.

3.6 IEA CCS modelling

In contrast to fusion carbon capture and storage (CCS) is becoming an increasingly important technology before 2050. CCS is the key technology that is considered by the Implementing Agreement IEA Greenhouse Gas R&D Programme, and it is one of the most important technologies that is considered by the IEA Clean Coal Centre. Data for CCS have been improved as a part of the development of the NEEDS Pan-European model, and the technology plays a key role in achieving the targets for emission reduction in the policy scenarios in the first published results of the model, see below Section 6.2.

The Carbon Dioxide Capture and Storage Modelling Workshop was initiated by the IEA Working Party on Fossil Fuels and arranged by the UK's Business, Enterprise and Regulatory Reform Department (BERR), 1 & 2 November 2007¸ at Schlumberger's offices in Crawley, UK. This workshop came to the following recommendations:

Noting the needs identified by the energy modellers and policy makers it was concluded that the IEA Working Party on Fossil Fuels could assist in meeting these requirements by supporting the following actions:

1. Establish an interactive forum involving modellers and policy makers to formulate the policy related questions concerning CCS that should be addressed through modelling studies and the approaches that could be used to best address these questions. This forum could be established through an annual workshop for policy makers and modellers under the auspices of the IEA WPFF. This would require preparatory work in which policy makers posed a set of questions to modellers and the modellers used the results of their work to deliver answers.

2. Establish a CCS information sharing and model review processes leading to understanding of model differences, improvements in modelling techniques, and increased transparency and quality in the data and assumptions that can be used to compare models. This action could be undertaken under the auspices of the IEA's ETSAP and Energy Technology Perspectives programmes.

3. Outreach activities should be conducted to those energy and climate change policy modellers who do not have the information with which to adequately incorporate CCS in their models. Such outreach is necessary in order to ensure that CCS is modelled on a level playing field with other greenhouse gas mitigation measures. This could be implemented through regional modelling workshops under the auspices of the WPFF and should convey information about the potential role of CCS, potential data sources, techniques and results of models that have effectively addressed CCS.

Until recently, CCS has not been considered as a part of the long-term Danish energy policy. However, in the publication from January 2007 "A visionary Danish energy policy 2025" it was stated: "Trials are at present being made on storing CO_2. If technological development indicates that this can be done cost effectively and without harm to the environment, the consequences for energy policy must be examined in greater detail. Naturally, this still lies some years in the future."

In the report on the new energy research programme published later in 2007, it is stated "The European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP) states in its Strategic Research Agenda (SRA) that CO2 emissions from electricity production can be lowered by 60% by 2050 through the development of carbon capture and storage technologies and that these CCS technologies will be commercially available in 2020." Among the EU's priorities the desire to concentrate on 10 to 12 demonstration plants for CO_2 capture up to 2015 is listed as the first item for visionary projects.

Several locations in Denmark have been identified as possible sited for CO_2 storages.

The major Danish power generators are participating in the CASTOR project under the EU 6th Framework Programme). This project is aimed at developing new CO_2 post-combustion separation processes suited to the problems of capture of CO_2 at low concentrations in large volumes of gases at low pressure. The processes will be tested in a pilot unit capable of treating from 1 to 2 tons of CO_2 per hour, from real fumes. It will be the largest installation in the world. The pilot plant is a modern CHP coal-fired plant operated by ELSAM (now DONG Energy, which also supplies the district heating system at Esbjerg, located near the Danish North Sea oil and gas fields. The project timescale is four years, 2004-2008.

The Danish power system operator Energinet.dk is partner in The Fossil Energy Coalition (FENCO)-ERA NET initiative, which commenced in June 2005 and is supported under the ERA-Net scheme.

FENCO-ERA is a Coordination Action (CA) within the EU 6th Framework Programme. Project title: Promotion of an Integrated European and National R&D Initiative for Fossil Energy Technologies towards Zero Emission Power Plants

The overall aim of FENCO-ERA is to network the national and regional R&D activities in the field of fossil energy conversion and carbon capture and storage (CCS) technologies in order to construct a durable ERA-NET. This topic is dedicated to examine the current state-of-the-art analysis of CCS technologies, to further develop economic modelling and to explore the economic potential of full deployment of CCS technologies within the portfolio of climate change mitigation options. It is further dedicated to analyse the economic potential of CCS under a wide range of socio-economic conditions, fossil fuel price developments and energy scenarios. This comprises following items for the different technology routes:

– Cost concepts, cost modelling and learning curve concepts
– Incentive schemes to promote the deployment of CCS
– National energy systems models and scenarios e.g. Markal, TIMES or others

Denmark is among the 11 countries participating in FENCO-ERA. This includes all countries around the North Sea, which offers several possibilities for CO_2 storage.

3.7 Technology learning

Quantitative technology learning became an important issue in ETSAP Annex VI in the late 1990s, which led to the development of MARKAL-ETL a nonlinear version of MARKAL in which the unit costs of technologies may decline with increasing total capacity as a result of endogenous technological learning, that is, down the learning curve. In the following Annex VII (Contributing to the Kyoto Protocol) ETSAP took part in experiments with endogenous technological learning using several technology-rich models within the European Union TEEM project. The main objectives of this synthesis of model experience were to derive common methodological insights; to indicate and assess benefits of the new feature, as well as the limitations of the method.

3.7.1 Endogenous technology learning in MARKAL

This work was followed in 2001, when the-Secretariat of the IEA initiated the project, Energy Technology Perspectives, which should draw on the broad range of-expertise by these activities. The project should report on scenario analyses-run with several MARKAL models on the national and supranational levels. With coordination by the Secretariat, experts from ETSAP will do the modelling. An important aspect of the work has been to develop data for technology learning to increase understanding of how the cost of energy from advanced and conventional technologies changes as these technologies are deployed in the market. A special version of the database user interface for MARKAL, ANSWER, was tailored to meet the needs of the International Energy Agency's Energy Technology Perspectives

The title of Annex VIII, 2002-05, was "Exploring Energy Technology Perspectives: Learning Strategies for Technological Development toward Sustainable Futures".

Om this background the most prominent contribution of ETSAP to The IEA G8 Plan of Action was the two large reports in 2006 and 2008 on *Energy Technology Perspectives: Scenarios & Strategies to 2050*.

A 15-region MARKAL model of the world energy supply and demand is the analytical backbone of the supply side of the analysis. For the ETP 2008, this has been complemented with spreadsheet models for the three end-use sectors: transportation, industry and buildings. These end-use sector models are detailed at the level of G8+5 countries and world regions.

The key parameter for learning curves is 'learning rate'. Learning rate implies percentage cost reduction for each doubling of installed capacity. Learning rate is used explicitly for nine renewable technologies in ETP 2006 (Table 4.13). For eight of these technologies (Biomass, Geothermal, Large and small hydro, Solar Thermal, Tidal, and wind onshore and offshore) the learning rate is 5 %., while the learning rate for Solar PV was reported to 18 %.

3.7.2 Energy Technology Perspective series

The first of these reports, ETP 2006, was based on assumptions from the reference case of WEO 2005 (energy price forecasts etc.), and ETP 2008 was based on WEO 2007. The long-term oil price assumptions are the same in ETP 2006 and ETP 2008, but in ETP 2008 the current price level has reached long-term assumption for ETP 2006. When the Energy Technology Perspectives project was initiated in 2001, oil prices were believed to remain below the 2000 level in a foreseeable future – about 30 $/barrel. However, the price in 2000 was about twice the price of the previous decade.

The price forecast until 2030 of the World Energy Outlook 2008, which was published only few months after ETP 2008, is about twice the assumption in WEO 2007.

The Energy Technology Perspectives 2008 study builds on the ETP 2006 and on the World Energy Outlook 2007 and expands the previous analyses considerably. For the first time the IEA has published scenarios that aim for a halving of energy related CO_2 emissions by 2050. Also energy related methane emissions and their reduction are discussed. This is also the first time that supply and demand side financing needs for technology deployment and commercial investments are elaborated in detail. In addition, the Baseline energy demand and emission projections has been revised upward, compared to ETP 2006.

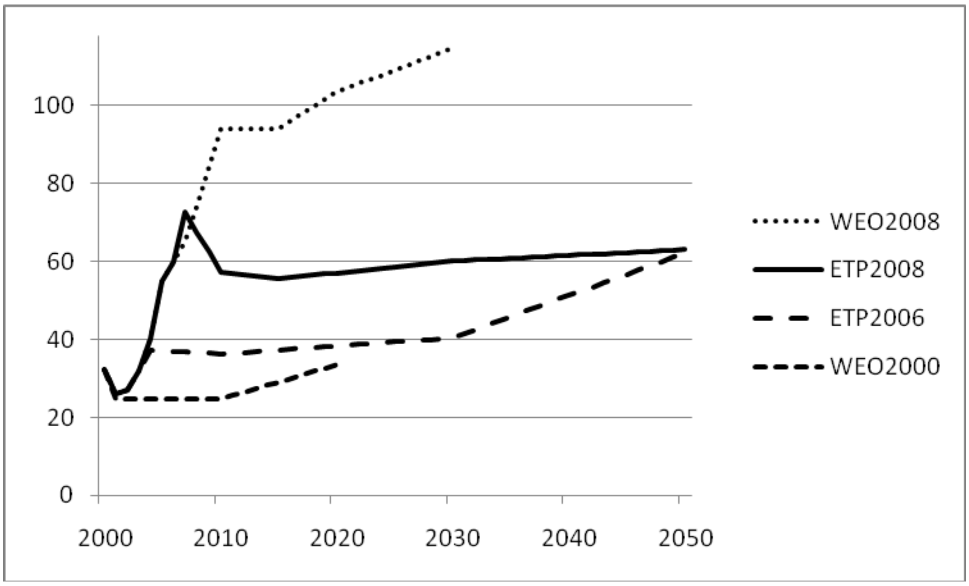


Figure 3.1. Crude oil price assumptions, $ 2005 per barrel.

The scope of the ETP modelling is different from the national or multinational models such as the NEEDS Pan-European model and the TIAM model. These models consider optimisation of the whole energy system in a region or globally, while the ETP focuses on detailed description of specific selected technologies, while the optimisation feature of the model is mainly used to evaluate the relevance and economic potential of the various technologies. The technologies for a detailed description and roadmap for stages of their development, R&D stage, Demonstration, Deployment, and Commercialisation are listed in Table 3.2

Table 3.2. Technologies considered in Energy Technology Perspectives 2008.

Supply Side	**Demand Side**
CCS fossil-fuel power generation	Energy efficiency in buildings and appliances
Nuclear power plants	Heat pumps
Onshore and offshore wind	Solar space and water heating
Biomass IGCC & co-combustion	Energy efficiency in transport
Photovoltaic systems	Electric and plug-in vehicles
Concentrating solar power	H_2 fuel cell vehicles
Coal: integrated-gasification combined cycle	CCS industry, H_2 and fuel transformation
Coal: ultra-supercritical	Industrial motor systems
2nd generation biofuels	

The roadmaps and technology descriptions are macro analysis in the sense that the focus are global and regional potentials and investment requirements, rather than micro data in the form of comprehensive technology parameters as needed for the MARKAL/TIMES type of modeling.

The Energy Technology Perspectives (ETP) Baseline Scenario was developed by extending the World Energy Outlook (WEO) Reference Scenario of the previous year from 2030 to 2050. As in the WEO Reference Scenario, the ETP Baseline includes the effects of technology developments and improvements in energy efficiency that can be expected on the basis of government policies already enacted.

Without new policies, global energy-related CO_2 emissions will increase very rapidly. In the WEO 2005 Reference Scenario, CO_2 emissions increase from 24.5 Gt in 2003 to 37.4 Gt in 2030. In the ETP Baseline Scenario, the growth in CO_2 emissions continues through to 2050, reaching 58 Gt CO_2.

In the short period from 2003 to 2005 global CO_2 emissions already increased by from 24.5 Gt in 2003 to 27 Gt in 2005. In the WEO 2007, the Reference Scenario assumes 42 Gt by 2030, and the ETP Baseline Scenario is reaching 62 Gt in 2050, which is 130 % higher than in 2005.

In both ETP 2006 and 2008 a series of Accelerated Technology scenarios (ACTs) were developed in addition to the Baseline Scenarios based on the World Energy Outlook published the previous year. The costs of achieving a more sustainable energy future in the ACT scenarios are expressed in terms of incremental cost per tonne of avoided CO_2 emissions in all countries, including developing countries.

The CO_2 emissions of the ACT scenarios of ETP 2006 are much lower than the Baseline for 2050 but slightly higher than the emissions in the base year 2003 (6 % for the technology-optimistic ACT Map scenario and up to 27 % for variants with lower nuclear or renewables or no CCS. The scenario assumptions for the ACT scenarios of ETP 2008 are stricter, as the emissions by 2050 in the ACT Map scenario are brought back to today's level.

ETP 2006 includes an additional scenario TECH Plus, in which CO_2 emissions by 2050 are 16 % lower than in the base year 2003. ETP 2008 goes much further to meet the most ambitious IPCC scenario aimed at keeping global average temperature increase below 2.4°C. To achieve this, global CO_2 emissions would need to be halved by 2050 compared to their current levels. At the Heiligendamm summit in Germany 2007 G8 leaders agreed to seriously consider a 50 % reduction target. To consider this target the more ambitious ETP BLUE scenarios was included to explore this target and its consequences for energy technology perspectives.

The financial needs of the CO_2 reduction scenarios are expressed in terms of estimated marginal emissions abatement cost by scenario in $ per ton of CO_2 reduced.

None of the technologies required for the ACT Map Scenario of ETP 2006 were expected – when fully commercialised – to have an incremental cost of more than USD 25 per tonne of avoided CO_2 emissions in all countries, including developing countries. For comparison, this cost is less than the average price for CO_2 permits under the European trading scheme over the first four months of 2006. A price of USD 25 per tonne of CO_2 would add about USD 0.02 per kWh to the cost of coal-fired electricity and about USD 0.07/litre to the cost of gasoline. The average cost per tonne CO_2 emissions reduction for the whole technology portfolio, once all technologies are fully commercialised, is less than USD 25.

The estimated marginal emissions abatement cost in the scenario variants with low nuclear or renewable are higher than in the ACT Map scenario, in particular in Europe, and the absence of CCS significantly increases the marginal cost of CO_2 emissions reduction.

In ETP 2008 the marginal cost and financing required to achieve these scenarios represent an important outcome of the study. The ACT Map scenario requires options with a marginal cost up to USD 50/t CO_2 (Gielen et al., 2008). This figure is double that reported in ETP 2006.

A number of reasons are given for this difference between the first and second ETP studies: higher economic growth projections, rising materials and engineering costs, new technology insights and the declining value of the United States dollar (all costs have been evaluated in US dollars).

For a period of six years the exchange rate went from 0.90 $/€ in 2001 to 1.37 $/€ in 2007 as annual averages, and similar variations in both directions have been seen before. So, the exchange rate between American and European currencies is a source of great uncertainty for technology studies. However, comparing the exchange rates in the two years formally used for the studies, there is little difference between 1,24 $/€ as average for 2004 used for WEO 2005 and ETP 2006 1.26 $/€ for 2006 used in WEO 2007 and ETP 2008.

The study concludes that end-use efficiency and a virtually CO_2-free power sector can yield emissions stabilisation in 2050 at today's level (the accelerated technology scenario ACT). However, halving emissions would also require significant fuel switching, CO_2 capture and storage in end-use sectors and steps to ensure that rapidly growing emissions from transport are not just slowed, but reduced. The BLUE scenarios are therefore requires earlier and more costly action.

3.7.3 Technology database for global and regional models

While the model used in the Energy Technology Perspectives consider a limited number of technologies that are described in details, a full-scale national model considers a large number of technologies for optimisation of investment and future operation. Each technology is described by a relatively small number of parameters (efficiency, availability, investment and operation costs, emission factors, etc.). Obviously, the values of these parameters and the consistency among competing technologies is essential for the results of the optimisation

Endogenous technology learning is not used for models with a large number of technologies. Instead, the feature for technology vintages is used, which may be based on results from studies using learning curves.

At the beginning of its activity ETSAP has produced three volumes of energy technology databases:

- Technology Review Report, KFA, October 1978; BNL, December 1979;
- Energy Technology Data Handbook, vol. 1 and 2, KFA STE nr. 18-19;
- Energy Technology Characterization, KFA STE nr. 30, 1982.

The compilation of a new energy technology database within ETSAP has been proposed several times since, but never implemented.

Instead, technology databases have been developed as a part of several studies using the model generators MARKAL and TIMES, as mentioned in Section 3.1 for the NEEDS-TIMES model. Another "Technology Repository" was developed for the US DoE SAGE model, which is the basis for the technology data in TIAM and EFDA-TIMES.

In the programme for ETSAP Annex XI one of the objectives for research and development is to establish an initial technology repository, directly or indirectly linkable to ETSAP models and tools; starting from existing models and databases.

At the first Executive Committee meeting under Annex XI, high priority was given to compiling a new energy Technology database (ETchDB). Although there exist other technology databases, but they are not injecting in the characterization of technology groups the insight necessary to use the data consistently in a model. It was mentioned that, for instance, the Nuclear Energy Agency issues every three years a collection of electricity costs by country and type, but does not explain the differences.

3.8 Modelling issues in Denmark

In 1980 Denmark – as represented by the newly established Ministry of Energy – signed the ETSAP Implementing Agreement and took part in Annex I “Energy Technology Systems Analysis Project”, under which the Energy Technology Data Handbook, mentioned above, was developed.

The key Subtask of Annex I was “Review and expand the technology characterizations developed for the lEA Energy Research, Development and Demonstration Strategy Project; perform sensitivity analyses, and study the competitiveness of selected technologies.”

Among the means to achieve the objectives of the Annex were the establishment of an lEA Energy Technology Systems Analysis Support Centre and temporary visits of officials from Participants to the Support Centre at KFA Jülich, Germany. At this time much of the effort was devoted to the availability of computer facilities and the physical transfer of the program code and data for the MARKAL model. The Danish participant in this work was Jesper Gundermann, who later became Climate Change Advisor for the Danish Energy Agency and active in climate change modelling within the IPCC until his early death in 2006.

The modelling work on MARKAL was not continued in Denmark. The technology focus of MARKAL was different from the priorities in Denmark. Large energy consuming industries are unimportant in Denmark; the largest industrial consumers are a single steel work and a single cement plant. Most industrial energy consumption in Denmark come from light industry and servicer, which are more suitable for econometric studies based on time series analysis rather than a technology-rich optimisation model.

The key issue for modelling in Denmark in the 1980s were the build up of infrastructure for natural gas and expansion of district heating systems for combined heat and power. These models must be based on site-specific analysis in a high geographical resolution with little room for technology optimisation.

3.8.1 Macroeconomic models and satellites

The continuous model development and model use in Denmark has followed these lines. A macroeconomic tradition was established in the 1970s for economic policy analysis by the Aggregated Danish Annual Model (ADAM). This model has been developed and expanded continuous. Originally limited to short and medium term analysis based on the Keynesian macroeconomic theory, the model now also cover longer term analyses with more emphasis on neo-classical economic theory. Several satellite models have been developed to ADAM. The first development in the 1980s focused on energy used in manufacturing industry, called INDUS. Later the Energy and eMission Model for

ADAM (EMMA) was developed for econometric-based forecasts of final energy consumption in most sectors. This model is continuously being used for energy demand forecasts for the next 20 years by the Danish Energy Agency and the Danish system operator for electricity and gas, Energinet,dk. In parallel with these activities Risø National Laboratory and the National Environmental Research Institute took part in several European projects on the development and use of the HERMES and E3ME macroeconomic models.

The key model used for the overall energy planning in the 1980 was a simple accounting model for all sectors with a merit-order/load duration curve function for the power sector with CHP with time-horizon 2000. This model was expanded with emissions calculation of SO_2 and NO_x, when these issues entered the agenda in the mid 1980s. Energy planning following the Brundtland report "Our Common Future" was based on a new accounting model in a series of spreadsheets. This model from 1988 was updated in 1992, 1994 and 1996. These models were developed and run by Risø National Laboratory for the Ministry of Energy. From 1988 a more detailed model, RAMSES, was developed within the Danish Energy Agency. RAMSES Version 6 from 2006 is a techno-economic model for electricity and heat in several regions with merit-order optimisation on an hourly basis. Most detailed for West and East Denmark, less detailed for Finland, Sweden and Norway. Investment in new capacity is exogenous. The main output is regional electricity prices, electricity and heat production, fuel requirement fuel and emissions (*www.ens.dk/sw68206.asp* **-** in Danish).

Having established the infrastructure for district heating connected to power plants and natural gas from about 1990, there is much room for technology optimisation of electricity and hest producing capacity as well as end use technologies in all sectors except most industries, which are using a variety of technologies that cannot be identified as specific energy consuming technologies. From the late 1980s Risø National Laboratory took part in several European projects on development and use of the EFOM model, mainly focusing on emission constraints. The main result of these activities was the development of national cost curves for SO_2, NO_x and CO_2 abatement, which has been a major topic for optimisation modelling over the past two decades.

3.8.2 Technology optimisation

From 1999 the development of a new optimisation model for analyses of the electricity and CHP sector in the Baltic Sea Region, Balmorel, was developed from scratch. The project was financed by the Danish Energy Research Programme as well as by the institutions from the countries around the Baltic Sea involved in the project. The project succeeded in developing the Balmorel model, and a number of studies were made with it. The model has since then consistently been developed and applied in various contexts, also outside the original focus area. The Balmorel model is coded in GAMS. The Balmorel GAMS code is 'Open Source', which may be downloaded from the project website, *www.balmorel,com* with a complete set of reference data. It may be used and modified following the conditions described on the website.

In contrast to Denmark, the MARKAL model that was implemented for the Nordic countries under ETSAP Annex I in the early 1980s became a widely used modelling tool in Sweden and Norway, while the EFOM model later became very much used in Finland with emphasis on large energy consuming industries, in particular the pulp and paper industry. In the whole period there have been contacts and common projects among Nordic modelling teams working with different types of models, and several models based in one of the Nordic countries have been extended to the other countries. There have been several common projects either within the Nordic Energy Research Programme under the Nordic Council of Ministers or within European Union Programmes. Although Norway and Iceland are not members of the European Union they were active members of the EU research programmes.

One of the collaborative projects, “Common Action and Electricity Trade in Northern Europe” was published in International Transactions in Operational Research 1998 with extensive references to modelling collaboration in the Nordic countries in the Mid 1990s and related studies, many of them from the ETSAP community, (Larsson et al. 1998).

A MARKAL model was developed for Denmark by the Norwegian Institute for Energy Technology (IFE) and reported in Krogh 1998. The large Swedish NORDLEDEN Project with participation by electricity companies and research institutes in Sweden, Norway and Finland “Cross-border grid-distributed energy trade and common action among the Nordic countries to facilitate CO_2 reductions” included also Denmark in the optimisation using the MARKAL-NORDIC model, (Unger et al., 2000, Rydén 2003). The MARKAL-NORDIC model is also described in ETSAP News, Vol. 8, No. 5, June 2005.

Finally, as mentioned above, all five Nordic countries are included in NEEDS-TIMES and RES2020 with direct participation by teams from Sweden (Chalmers), Finland (VTT-TEKES) and Denmark (Risø DTU)

3.8.3 Wind power

Modelling an energy system with a significant contribution by wind power has become a key task for modelling the electricity system task in Denmark, because nearly one-fourth of the electricity consumption in Western Denmark is generated by wind on an annual basis.

Balmorel was the starting point for model development under the WILMAR research project supported by the European Commission under the Fifth Framework Programme from 2002 to 2006. The key task of this project was to analyse the integration of wind power in a large liberalised electricity system in Northern Europe, covering four Nordic countries and Germany. Within WILMAR a long-term model was developed to address further integration of wind power in Northern Europe, where some regions are dominated by hydro power production from reservoirs. Increased wind power generation in other regions may lead to bottlenecks in the transmission networks, which may increase costs and lead to regional price differences. The model is using data for wind and electricity demand on an hourly basis, hydro reservoirs are simulated on a weekly basis, and the model may be simulated over several years. The model analyses the fluctuations and the partial unpredictability in the wind power production, and how other units in the power system have to be operated more flexibly to maintain the stability of the power system. Technically this means that larger amounts of wind power will require increased capacities of spinning and non-spinning power reserves and an increased use of these reserves.

It follows from this description that endogenous investment in new capacity is not included in the WILMAR long-term model. This is the key issue in MARKAL, TIMES and Balmorel, but these models can handle much less operational details. Thus, aggregate parameters developed from models like WILMAR will be needed to address wind power in models with endogenous investment. This issue have been considered within the TIMES model for the RES2020 project, but no satisfactory solution have yet been found.

3.8.4 Technology catalogues

The development and maintenance of technology data has been a continuous activity in Denmark since the early 1980s, focusing on electricity and heat generation technologies and sometimes also on end-use technologies. A series of technology catalogues have been developed by Danish consultancy firms with some five years intervals. The latest issued was published in English in 2005 as one of the background report for the Energy Strategy 2025 (DEA, 2005).

4 Flow optimisation energy models

The ETSAP model tools belong to the type of technology-rich bottom-up optimisation models. The energy system is described by a network of energy flow, which is optimised using a mathematical algoritm.

4.1 Main principles

The basic elements of the ETSAP model tools are summarised in Figure 4.1. The key elements of a *Reference Energy System* are illustrated in the diagram. The *processes* (energy technologies) transform upstream *commodities* (energy carriers, materials or emeissions) to downstream commodities.

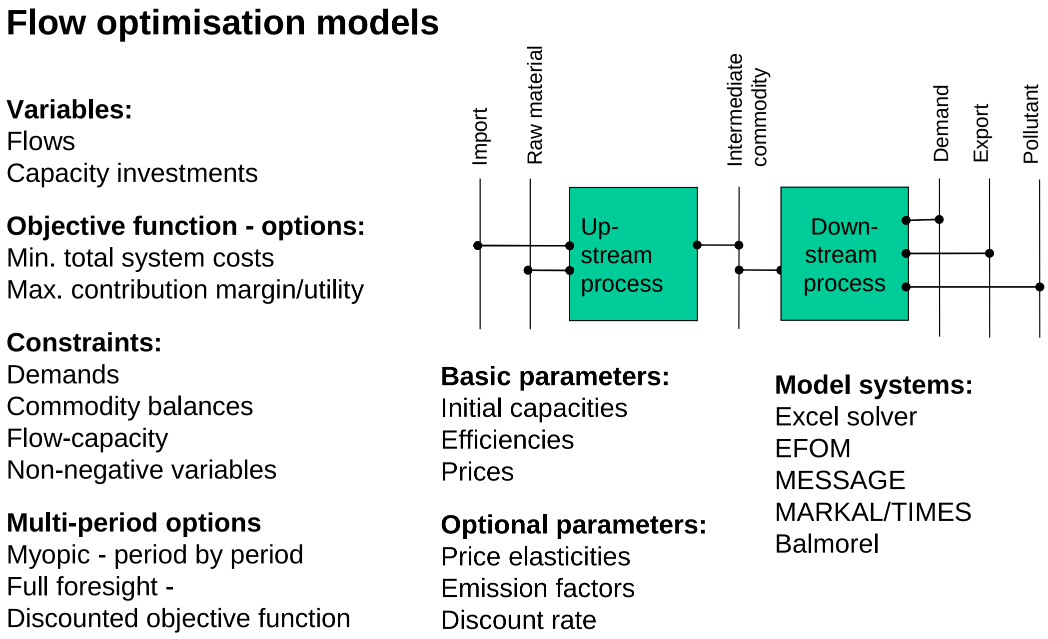


Figure 4.1. Flow optimisation models in principle

The relations between upstream and downstream energy carriers are normally given by *efficiencies*, typically less than 1, while the relations between pollutants and energy input are given by *emission factors*. The system is driven by *demand forecasts* using a mathematical algorithm, typically linear programming. The reference energy system within a region is described by the initial capacities of existing technologies. These capacities will be reduced over the tears and replaced by *new technologies* that are added to the system. The system must comply with a set of technical constraints, such as *commodity balances* between output and input for all processes, *flow-capacity* constraints requiring the necessary available capacity for the flows of commodities.

The variables – normally *non-negative* – to be calculated by the *optimisation* are commodity *flows* and capacity investment for processes representing new technologies. The objective function to be optimised depends on the type of the model.

In the classical and most simple model it is minimising *total system cost* necessary to meet the exogenous demand forecast. Key parameters in the objective function are *prices* for the most upstream commodities, typically primary fuels, and investment and operating cost of processes.

The demand for energy may be an endogenous variable to be determined by the optimisation. This will change the objective function to maximisation of the *contribution market*, gross profit, or maximum utility, which may be quantified as the sum of consumers' and producers' benefits in a market equilibrium mode.

If the demand for energy is dependent on the price of delivered energy, *price elasticities* are used to determine the demand function.

In multi-period models the optimisation may be calculated period-by-period, so the result of one period will be initial capacities for the next period (myopic). Alternatively, the optimisation may cover the whole period within the time horizon (*full foresight*). In this case future costs and revenues will be *discounted*.

4.2 TIMES software

The EFOM and classical MARKAL models, which are the basis for the TIMES model, were simple cost minimisation models driven by exogenous demands. In contrast to these models, TIMES is far more flexible, in particular concerning the seasonal and diurnal break-downs of the year, which were limited to four or six time slices in the old model, but fully flexible in TIMES.

Elastic demands were introduced in early versions of TIMES, and TIMES has gradually developed to include most of the features of the MARKAL Family of models as described in Table 2.3.

Table 4.1. TIMES updates with new functionality.

Version	Month	Function
1.3.1	1/2005	Added prototype climate module.
1.4.4	10/2005	Introduced Damage Functions.
1.5.0	11/2005	Added Macro module to TIMES and introduced Stochastic TIMES (used for the climate module)
2.0.0	01/2006	Documentation note
2.1.8	11/2006	Enhancements in Climate Module
2.4.0	10/2007	Implemented support for using GAMS savepoint / loadpoint facility.
2.5.0	11/2007	Implemented Tradeoff Analysis Facility under stochastic model.
2.5.7	03/2008	Support for three alternative objective function variants completed.
2.8.0	08/2008	First Implementation of Time-Stepped TIMES (limited foresight).

The recent versions of MARKAL and all versions of TIMES are written in the General Algebraic Modelling Language (GAMS), which is used to formulate problems that is solve by a variety of mathematical solvers. The basic user interface for GAMS is simple text files. However, for larger GAMS models a user shell written in Excel, Access or a traditional programming language will be useful.

GAMS is developed and sold by GAMS Development Corporation (*www.gams.com*). The software comes with a text editor GAMS-IDE, which is mainly for model development. The TIMES source code consists of more than 200 files, which contains formulas, but no data. Any TIMES model consists of a large amount of data that are organised as described in Figure 4.1.

ETSAP supports the development of two different user shells for both MARKAL and TIMES, ANSWER developed by Ken Noble, Noble Soft, Australia and VEDA developed by Amit Kanudia, KanORS, Canada/India. These user shells are propriety software, which are available mainly for participants in collaborative projects using MARKAL or TIMES, or licensed to other users.

The TIMES code will be updated automatically together with VEDA from the KanORS website using the Web Installer, which normally runs very smoothly. In addition to the updates with new functionalities as shown in Table 4.1, there have been frequent updates with minor bug fixes and enhancements.

The source codes for The MARKAL and TIMES model generators are available free of charge, upon providing a signed copy of the ETSAP Letter of Agreement to the ETSAP Primary Software Coordinator (ETSAP PSC, currently DecisionWare, Inc.), see *www.etsap.org/Tools.asp*.

An important result of ETSAP Annex VIII/IX was an extensive and comprehensive documentation for TIMES, consisting of three main volumes:

– Part I: TIMES Concepts And Theory,
– Part II: Reference Manual
– Part III: GAMS Implementation

This documentation is freely available for the ETSAP website, together with documentation of updates and extensions to the core feature of TIMES, see *www.etsap.org/documentation.asp*.

– Version 2.1. Information note. June 2006.
– Climate: TIMES Climate Module. Revised October 2007.
– Control Switches: TIMES Version 2.5 User Note. User Control Switches in TIMES. Revised September 2008
– Cost Bounding: TIMES Version 2.5 User Note. Specifying Cost Bounds in TIMES. February 2007
– Damage: TIMES Version 2.0 User Note: TIMES Damage functions. November 2005
– Elastic Demands – Shaping: TIMES Version 2.5 User Note Shaping of Demand Elasticities in TIMES. February 2008.
– Interpolation Settings. Inter/Extrapolation of Input Parameters in TIMES. December 2007.
– Load Point: GAMS Savepoint and Loadpoint in TIMES, September 2007
– Macro: Documentation of the TIMES-MACRO model (Draft). February 2006
– Objective Function Variants: TIMES Version 2.8 User Note. TIMES Objective Function Formulations. August 2008.
– Stochastic: TIMES Version 2.5 User Note. Stochastic Programming and Tradeoff Analysis in TIMES. Revised November 2007

– New Parameters under VEDA: TIMES Version 2.5 User Note. New parameters for TIMES under TIMESVDA. February 2008 (update of note from April 2005).

Several of these updates and extensions were developed within the NEEDS project and linked to the improvements of the front-end of the VEDA user shell. Others are improvement of the mathematical formulation of the model, e.g. variants of the objective function. Benchmark shows that the standard formulation of the objective function can lead to notable differences in investment & fixed costs, in particular the choice of periods may affect technology competitiveness. One of the alternative formulation of the objective function (the LIN option) can even give identical model results regardless of the milestones used in the model.

Two type of GAMS text files are used to run the TIMES model, The "Run" file calls the TIMES model generator and includes a number of data files that specifies the reference energy system (`base.dd`), new technologies (`b-newtechs.dd`) and several files for scenario specifications, consisting of demand projections (`demproj.dd`), fuel price forecasts (e.g. `fuel_price.dd`), various user-specified constraints (e.g. `uc_sector.dd`) for the different sectors of the reference energy system or policy scenarios, plus some more general system parameters (`syssettings.dd`) and milestone years used for optimisation and reporting.

For each run of the model a single run file and several -.dd files are used, which contains all additional data used in the model. The system is started by a commend file, which runs in a command window showing the progress of the model execution.

Table 4.2. Contents of GAMS text files used to run TIMES.

Run file

Initialisation

```
SET ALL_TS/ANNUAL seasons seasons-diurnal /
$BATINCLUDE base.dd
$BATINCLUDE b-newtechs.dd
$BATINCLUDE demproj.dd
$BATINCLUDE fuel_price.dd
$BATINCLUDE uc_sector.dd
$BATINCLUDE uc_policy.dd
$BATINCLUDE syssettings.dd
SET MILESTONYR /2000,2005,2010,2015,2020,2025,2030,2040,2050/;
$SET RUN_NAME 'DKw20h'
```

.dd files

```
SET
/elements/
/combined elements from previously defined sets/
PARAMETER
Parameter name
combined elements from previously defined sets – value
```

Vtrun.cmd

```
Call GAMS folder DKw20h.RUM IDIR=folder GDX=DKw20h
GDX2VEDA DKw20h TIMES GAMS code folder\times2veda.vdd DKw20h
```

The time needed to run a single-country model in NEEDS-TIMES is normally 1-5 minutes, but very dependent of the particular choice of scenarios. The time needed for multi-regional models increase progressively with the number of regions. The time needed for these models, e.g. the Pan-European model in a single optimisation or the TIAM 15-regions model is also very dependent on the optimisation software – from less than an hour using CPLEX with BARRIER to more than 20 hours with CPLEX with DUAL SIMPLEX.

4.3 The VEDA-TIMES user shell

"The VErsitile Data Analyst (VEDA) supports both MARKAL and TIMES. VEDA consists of two independent but closely related software, VEDA Front-End (VEDA-FE), which overseas the management of the input data and submitting of model runs, and VEDA-Back-End (VEDA-BE) used to analyze the results of the model runs. VEDA was explicitly developed to support the increased complexity associated with developing and applying large multi-region models. VEDA is now being used for the major multi-region modelling initiative including the global models of the Energy Information Administration (SAGE), European Union (NEEDS), and European Fusion Development Agreement (EFDA), and the New England MARKAL undertakings." (ETSAP Newsletter 8-6, July 2005)

A major effort within ETSAP Annex X has been the further development of the VEDA user shell, which was done as a task within the projects for the development of NEEDS-TIMES, EFDA-TIMES and TIAM. A smooth procedure for update of VEDA as well as the TIMES model generator was developed and has been used by all modellers within these projects.

An important new feature is the VEDA Front End Navigator shown in Figure 4.2. The example shows the files used for Danish model within the Pan-European model. The left part of Figure 4.2 shows all the templates used for input to the model. The upper left window lists the Base-Year Templates (Excel workbooks) for the five sectors, ELC (electricity and heat), IND (industry), RCA (residential, commercial, agriculture), SUP (resources, mining, refineries and fuel trade), and TRA (transport). In the full Pan-European model there are Base-Year Templates for all 30 countries, currently included in the model. The upper right window, SubRES shows the templates for new technologies. These are usually common for all countries. However, national specific parameters are listed in a separate 'Transformation template'. The lower left window shows a number of scenario templates, mostly dealing with parameters for forecast years. The three remaining windows may be used for special types of scenarios. The 'Trade Scen' window is important for multiregional models, e.g. for capacities of transmission lines. Finally some general technical parameters are found in the templates BY-Trans and SysSettings.

The bottom in the middle – now showing that all templates have been successfully imported, "ALL OK", is used for synchronising the templates, whenever modified with the hidden database in Microsoft Access. The contents of all templates can be modified by clicking on the filename in the Navigator.

The right part of Figure 4.2 shows The Front End Case Manager, which is used to specify and name cases for optimisation. The bottom "Solve" save all relevant GAMS files (see Table 4.2) and starts a GAMS session. Depending of the size of the problem and the hardware and software resources this may take from few seconds to several hours.

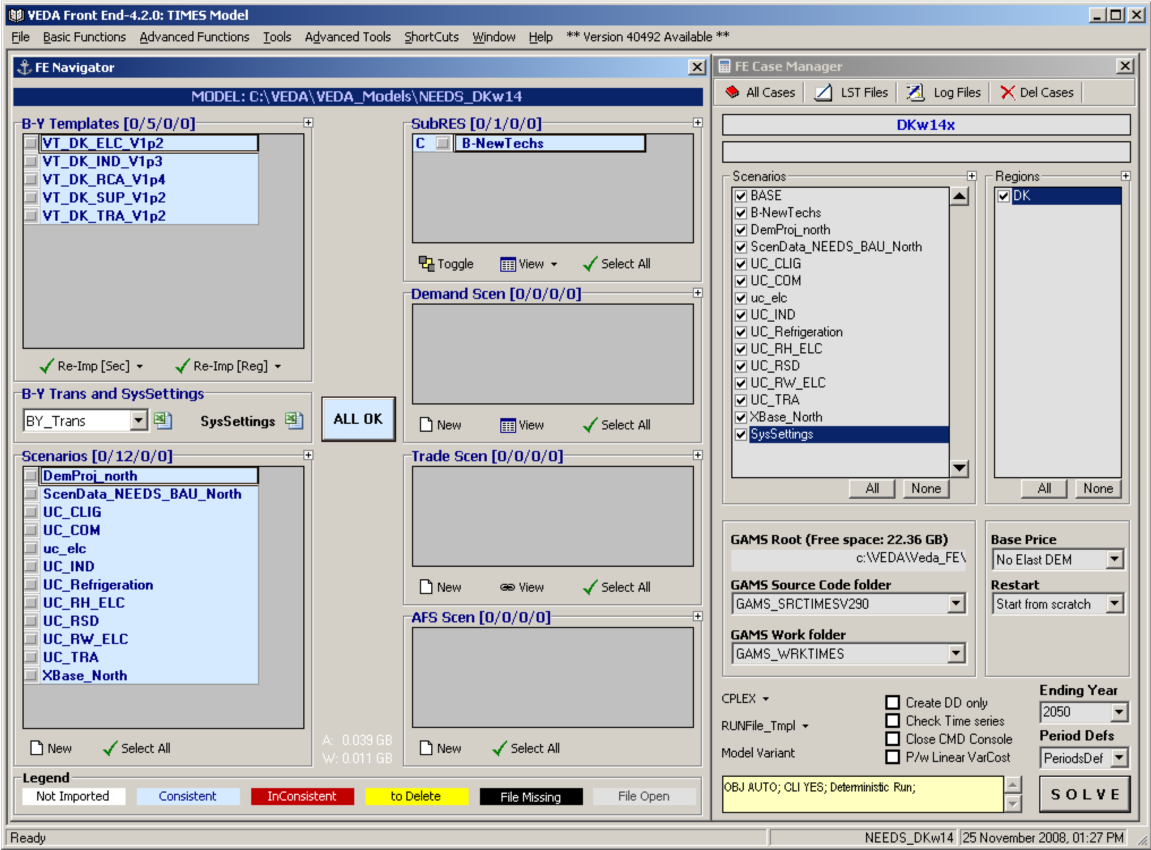


Figure 4.2. VEDA Front End navigator. NEEDS-TIMES for Denmark.

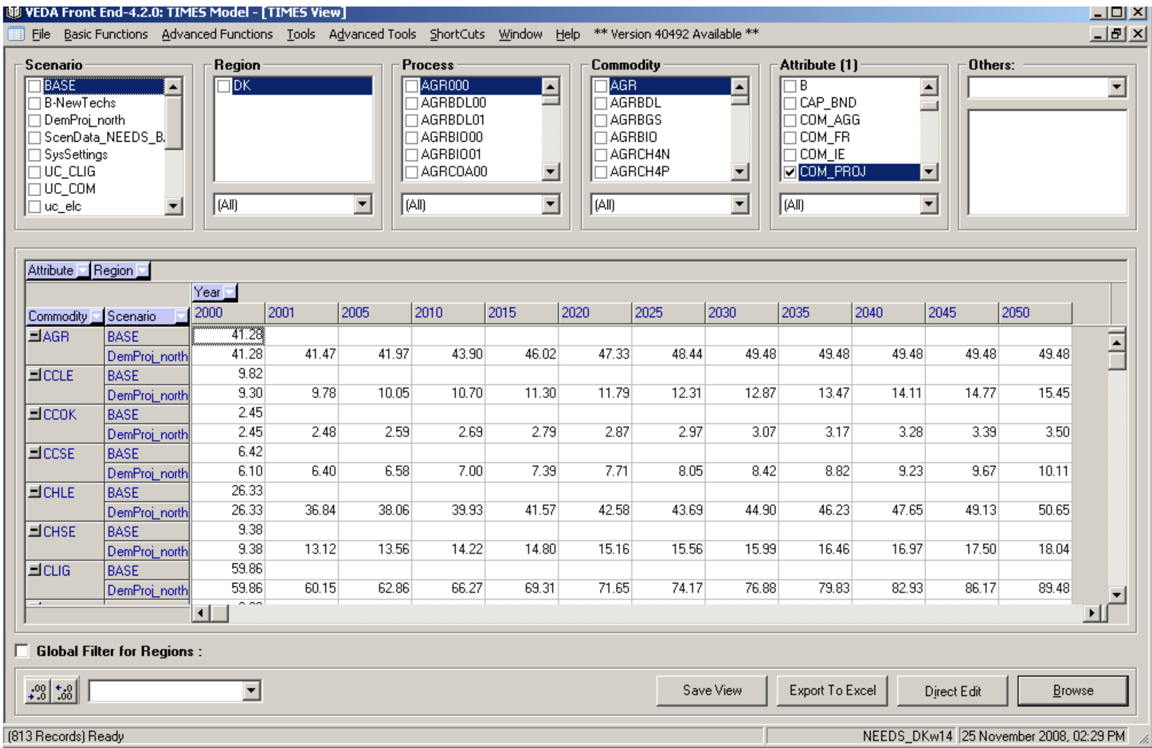


Figure 4.3. VEDA Front End browser, NEEDS Pan-European model. Demand forecast for Denmark

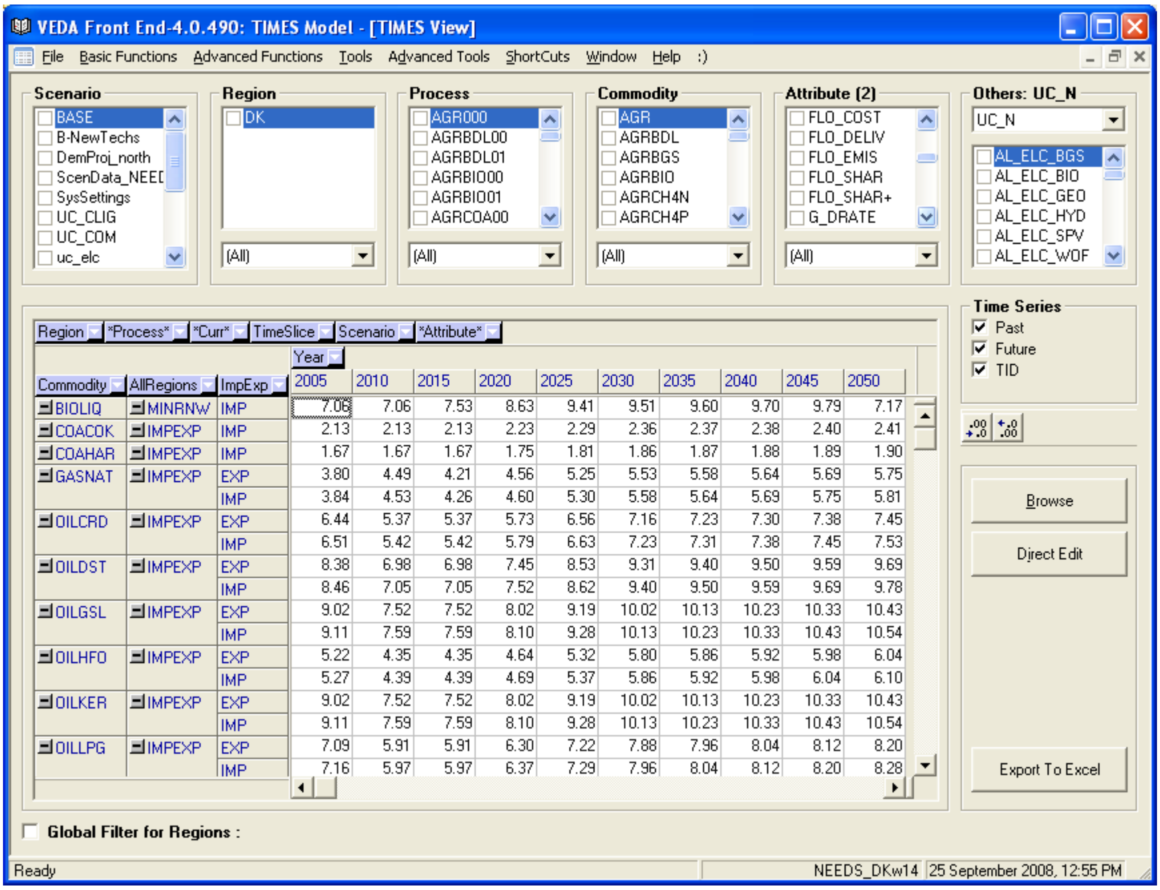


Figure 4.4. VEDA Front End. NEEDS Pan-European model. Import and export prices for fuels.

All data input for the TIMES model generator can be found in the templates. However, these have been developed over several years by several teams, so they are not necessarily standardised and suitable for a comprehensive documentation for model input in a specific scenario. This is more easily done by the VEDA-FE browser facility. Figure 4.3 shows demand forecasts for one of the scenario and for the Base-Year templates. This is also an important tool for debugging. In this case to make sure that the demand forecasts are consistent with the base year calibration. In the following Figure 4.4 the fuel price assumptions are documented.

The GAMS results are written into a set of text files, which may be imported into a wide range of tools for further analyses. VEDA Back End is a database system, which is linked to VEDA Front End. The first check of each new case results should be the value of the objective function and the existence of ‘dummy imports’. The latter is used to prevent that too many cases are stopped by infeasible results, because some constraints could not be met. It means that if some demand cannot be met by the modelled energy system, some commodities will be imported at a high price.

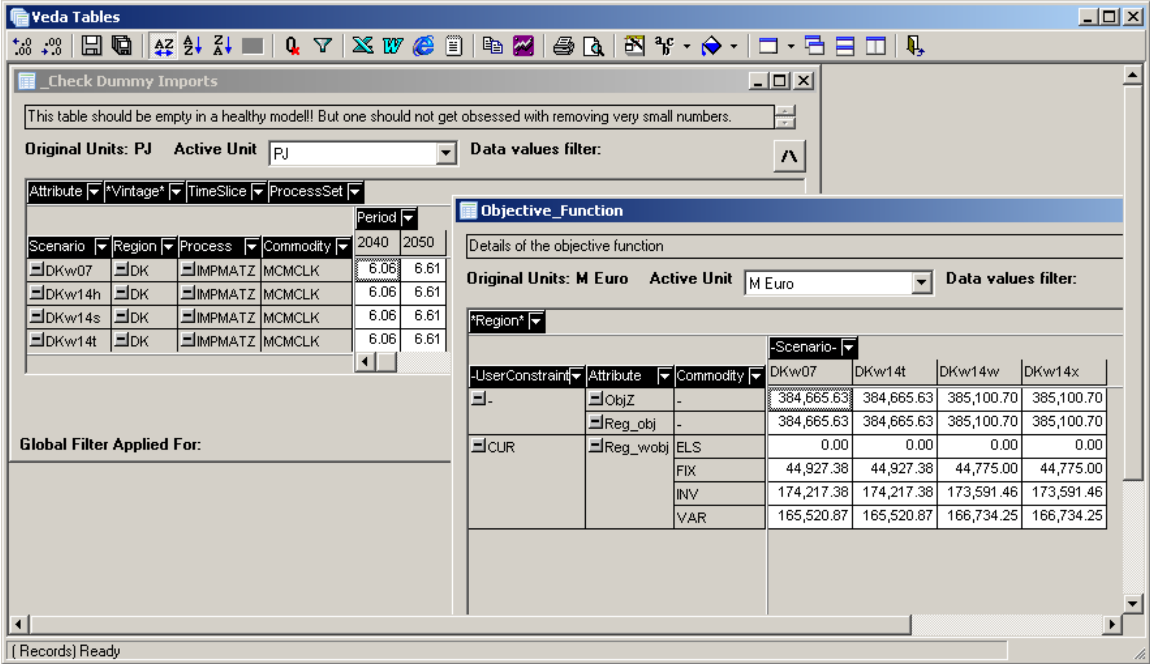
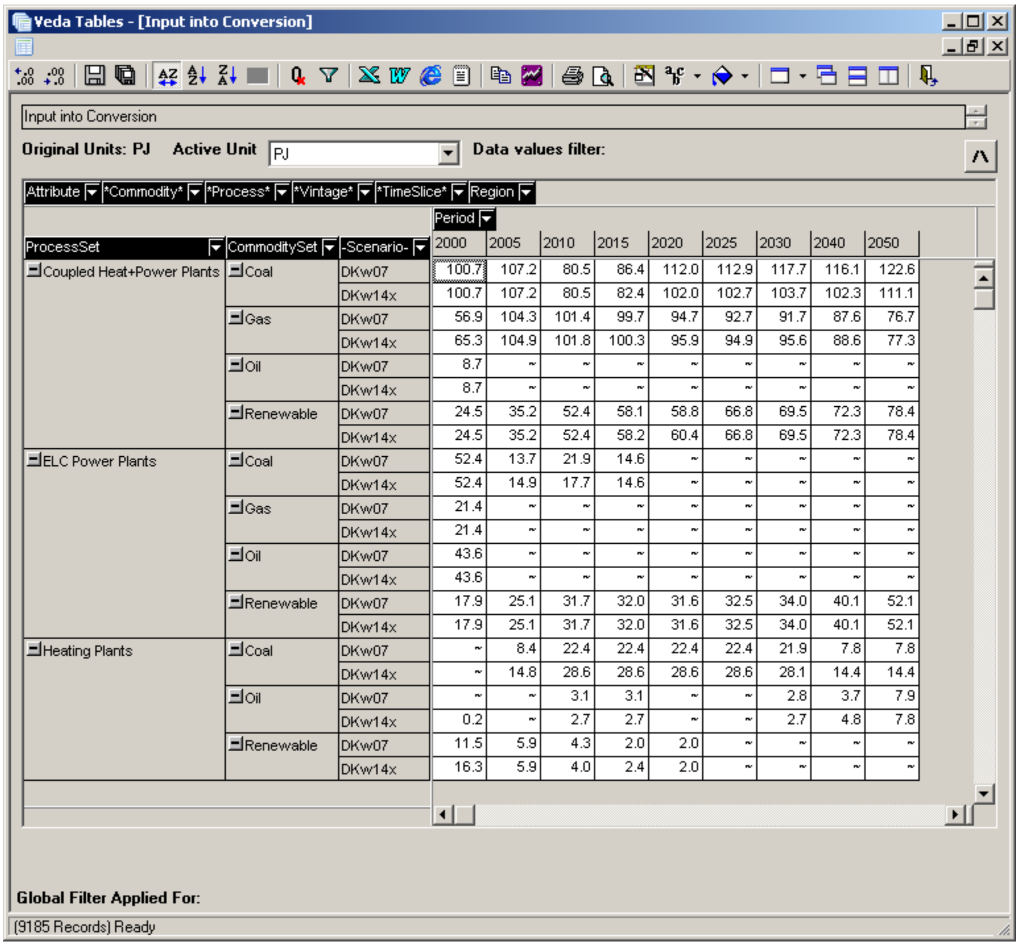


Figure 4.5. VEDA Back End. Debugging tables.

These 'dummy imports' may be avoided by relaxing some constraints, e.g. by adding more capacity in the base year for selected technologies, or reducing the demand forecast for some commodities. Large dummy imports in the base year or the first milestone years will often give results that are not suitable for presentation. However, minor dummy import in sectors outside the main focus of analysis should not harm the presentation. The example in Figure 4.5 shows that there is dummy imports of clinker (intermediate product in the cement industry) in the Danish model for the two last milestone years. To avoid this, a more detailed analysis of the cement industry will be needed. This analysis has a low priority for the development of the Danish model. This problem may by solved by other modelling teams or in a later update of the software. The table Objective_Function in Figure 4.5 compares the results of different runs using the same assumptions from the first release of the Pan-European model, and after updates of VEDA-FE. The model results were identical after minor updates of VEDA, but the major update from VEDA version 3 to Version 4 gave slightly different results for the objective value. The differences between the cases may be analysed further by comparing the optimisation results for the commodities that are most sensitive to the choice of parameters. Typically, there is most room for optimisation in the energy conversion sector (electricity and heat generation). Figure 4.6 shows that, although that the differences in objective values are small, the difference in fuel input is not negligible. In a reference scenario with few constraints on fuel input the results for coal and gas could be quite volatile. On the other hand, the results for renewable is more stable, because the input of renewable is more dependent on exogenous constraints rather than free optimisation.

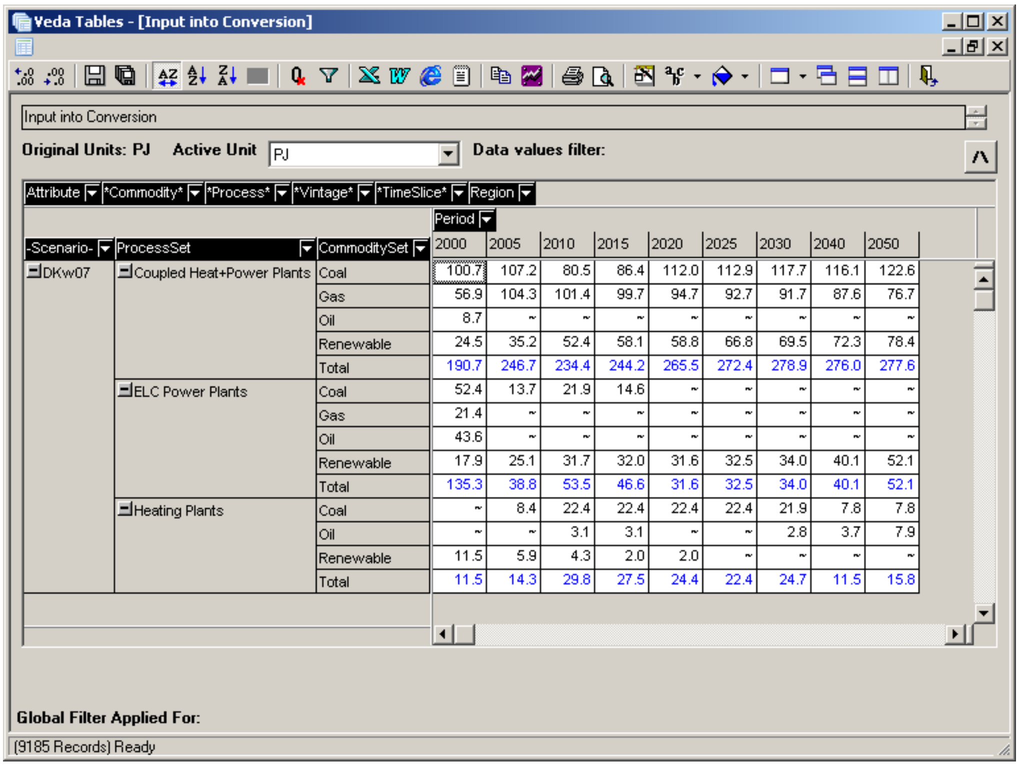
The next Figure 4.7 shows the result for one of the cases shown in Figure 4.6 that are rearranged in a form suitable for presentation. VEDA-BE contains various features for graphical presentation, or the tables may be exported to Excel for further analysis.

As mentioned above, the VEDA user interface have been developed and used for several models developed or supported by the ETSAP tools. These are summarized in Table 4.3.



ProcessSet	CommoditySet	-Scenario-	2000	2005	2010	2015	2020	2025	2030	2040	2050
Coupled Heat+Power Plants	Coal	DKw07	100.7	107.2	80.5	86.4	112.0	112.9	117.7	116.1	122.6
		DKw14x	100.7	107.2	80.5	82.4	102.0	102.7	103.7	102.3	111.1
	Gas	DKw07	56.9	104.3	101.4	99.7	94.7	92.7	91.7	87.6	76.7
		DKw14x	65.3	104.9	101.8	100.3	95.9	94.9	95.6	88.6	77.3
	Oil	DKw07	8.7	~	~	~	~	~	~	~	~
		DKw14x	8.7	~	~	~	~	~	~	~	~
	Renewable	DKw07	24.5	35.2	52.4	58.1	58.8	66.8	69.5	72.3	78.4
		DKw14x	24.5	35.2	52.4	58.2	60.4	66.8	69.5	72.3	78.4
ELC Power Plants	Coal	DKw07	52.4	13.7	21.9	14.6	~	~	~	~	~
		DKw14x	52.4	14.9	17.7	14.6	~	~	~	~	~
	Gas	DKw07	21.4	~	~	~	~	~	~	~	~
		DKw14x	21.4	~	~	~	~	~	~	~	~
	Oil	DKw07	43.6	~	~	~	~	~	~	~	~
		DKw14x	43.6	~	~	~	~	~	~	~	~
	Renewable	DKw07	17.9	25.1	31.7	32.0	31.6	32.5	34.0	40.1	52.1
		DKw14x	17.9	25.1	31.7	32.0	31.6	32.5	34.0	40.1	52.1
Heating Plants	Coal	DKw07	~	8.4	22.4	22.4	22.4	22.4	21.9	7.8	7.8
		DKw14x	~	14.8	28.6	28.6	28.6	28.6	28.1	14.4	14.4
	Oil	DKw07	~	~	3.1	3.1	~	~	2.8	3.7	7.9
		DKw14x	0.2	~	2.7	2.7	~	~	2.7	4.8	7.8
	Renewable	DKw07	11.5	5.9	4.3	2.0	2.0	~	~	~	~
		DKw14x	16.3	5.9	4.0	2.4	2.0	~	~	~	~

Figure 4.6. VEDA Back End. Comparing results for two versions of VEDA Front End.



-Scenario-	ProcessSet	CommoditySet	2000	2005	2010	2015	2020	2025	2030	2040	2050
DKw07	Coupled Heat+Power Plants	Coal	100.7	107.2	80.5	86.4	112.0	112.9	117.7	116.1	122.6
		Gas	56.9	104.3	101.4	99.7	94.7	92.7	91.7	87.6	76.7
		Oil	8.7	~	~	~	~	~	~	~	~
		Renewable	24.5	35.2	52.4	58.1	58.8	66.8	69.5	72.3	78.4
		Total	190.7	246.7	234.4	244.2	265.5	272.4	278.9	276.0	277.6
	ELC Power Plants	Coal	52.4	13.7	21.9	14.6	~	~	~	~	~
		Gas	21.4	~	~	~	~	~	~	~	~
		Oil	43.6	~	~	~	~	~	~	~	~
		Renewable	17.9	25.1	31.7	32.0	31.6	32.5	34.0	40.1	52.1
		Total	135.3	38.8	53.5	46.6	31.6	32.5	34.0	40.1	52.1
	Heating Plants	Coal	~	8.4	22.4	22.4	22.4	22.4	21.9	7.8	7.8
		Oil	~	~	3.1	3.1	~	~	2.8	3.7	7.9
		Renewable	11.5	5.9	4.3	2.0	2.0	~	~	~	~
		Total	11.5	14.3	29.8	27.5	24.4	22.4	24.7	11.5	15.8

Figure 4.7. VEDA Back End. Results for presentation.

VEDA-BE is used to read the results of models runs by the MARKAL and TIMES model generators. The front end for these models may be either VEDA-FE, ANSWER or any other front end developed by the user.

Table 4.3. ETSAP models using VEDA

Model	Programme	Regions	Horizon	Foresight	Focus
NEEDS-TIMES	EU FP6 NEEDS	29 European countries (+Pan-European)	2050	Perfect	All energy, Climate module, LCA, externalities.
RES2020-TIMES	Intelligent Energy Europe	29 European countries (+Pan-European)	2020	Perfect	RES-E, Biomass heat/cool
TIMES-EE (-EG)	IER-Stuttgart, (EUSUSTEL, etc.)	EU15 ++	2030	Perfect	Electricity, (gas)
SAGE (MARKAL)	US-DOE, Energy Information Administration.	Global 15 regions	2050	Myopic	SAGE: System for Analysis of Global Energy markets
EFDA-TIMES	EFDA	Global 15 regions	2100	Perfect	Fusion + alternatives
TIAM- TIMES Integrated Assessment Model	ETSAP, Canadian Research Council	Global 15 regions	2100	Myopic, Stochastic Programming	Technology, energy trade, link with GEM-E3, climate module, carbon sequestration

4.4 ETSAP Tools training

Support to ETSAP tools users is an important task within ETSAP Annex XI, see Section 2.7. The documentation will be improved as follows:

- Update and extension of the “Getting started with TIMES-VEDA” guide
- Drafting a similar “Getting started with TIMES ANSWER” guide
- Review and improve the base users’ guidebook of TIMES and MARKAL, including all new feature and the documentation of the price formation equations
- Documentation of the value flows equations
- Guidelines for benchmarking large technical economic models and scenarios

In addition, limited support has become available at support@etsap.org. Non-ETSAP institutions who are interested in receiving more substantial support for the development of models based on the ETSAP model generators may request ETSAP Support for the payment of an annual fee, see www.etsap.org/documentation.asp.

ETSAP offers training courses at the introductory, intermediate and advanced levels to introduce new users to its model generators and user interfaces. The tutorial to be downloaded from www.etsap.org (at the time of writing – November 2008 – from www.etsap.org/ArchNews.asp), “Getting started with TIMES-VEDA, Draft 2.1, January 2008” by: Maurizio Gargiulo with contributions of Gary Goldstein, Amit Kanudia, Antti Lehtila, Uwe Remme, GC Tosato.

The tutorial is divided into two steps

- TIMES_TUTORIAL showing the key elements of the VEDA_FE templates and VEDA_BE
- TIMES_DEMO a simplified energy system with four sectors covering supply conversion and demand, with practical explanation of the model structure and, parameters, and important types of processes and commodities – including steel processes and CHP.

This document builds on the experience that was gained during the development of the Pan-European model. The document is based on VEDA_FE Version 3. The major update to VEDA_FE Version 4, which was released in May 2008, is not considered in the document and the TIMES_TUTORIAL model. This update introduces explicit declaration of both processes and commodities instead of implicit declaration of processes and explicit declaration of commodities.

The TIMES_DEMO model is distributed with VEDA as part of the VEDA software package. It is normally updated to comply with the latest released version of VEDA-FE.
The document contains three appendices:

- Getting Started with Problem – Defining and Describing the Area of Study. This appendix is a primer on energy systems analysis.
- Getting Started with the Software. This chapter aims at guiding the user through the installation procedures of the various software components. It ends with the procedure for checking that all pieces of software are installed correctly.
- APPENDIX C – Further software details. Describing the organisation of the model in VEDA, syntax of VEDA templates, declarations of TIMES parameters in VEDA Templates, and methods of interpolation and extrapolation among years specified in the templates and the milestone years used in the optimisation.

4.5 Discount rates

The NEEDS Pan-European model assumes a general discount rate at 4 % p.a. This is very low compared to the requirements by private investors, but similar to the discount rates used for traditional energy planning studies for a regulated market. In several recent long-term studies focusing on new technologies a constant 4 % discount rate throughout has been requested by the Commission, e.g. the SAPIENT project.

Different discount rates have been applied in models and studies, which have been used recently as references for the scenario building.

The SAPIENT project considered technology opportunities, R&D and market experience, referring to different modelling studies. In one of these model studies ”Two-factor learning curves in ERIS” by Leonardo Barreto (IIASA-ECS) and Socrates Kypreos (PSI), a 5 % discount rate is used in all calculations. For other models in the study, ISPA meta-Model and TIMES-WEU, a constant 4% discount rate throughout as requested by the Commission. Also in the following study, SAPENTIA, the overall discount rate used is 4 %, in line with the Commission’s request for the SAPIENT project. However an 8 % discount rate was used for a harmonised framework for the comparison of production costs of electricity.

The use of discount rates in the PRIMES, which has been used for numerous studies for the European Commission is described as follows:

“The discount rate plays an important role within the PRIMES model. It is a crucial element in the determination of investment decisions by economic agents regarding energy using equipment. Three (real) rates are currently used within the model. The first, used mostly for large utilities, is set at 8 %; the second, used for large industrial and commercial entities, is set at 12 %; the third, used for households in determining their spending on transportation and household equipment, is set at 17.5 %.”

The 8 % real discount rate used in PRIMES for large utilities should be considered consistent with a liberalised electricity and gas market, which will continue to be dominated by large entities with a long time-horizon.

The choice of discount rate for long-term models is difficult from a theoretical point of view. It may also have significant practical impact on the results, because higher discount rates will discourage capital-intensive technologies, such as nuclear and renewables.

4.6 Stepwise development of national and Pan-European models

The first step for developing the NEEDS-TIMES model for – now 30 – European counties was the set up of a common Reference Energy System, which were implemented into a set of base-year templates in a common structure plus a SubRES template containing all new technologies that are considered for the model. Demand forecast are made by a set of ‘demand drivers’, i.e. population, work force, aggregate or sectoral GDP, etc. from economic forecasts. The stepwise development has been summarised as follows:

- Common Base-Year templates with Eurostat 2000 data
- Common data for new technologies
- Demand forecasts by GEM-E3, POLES, etc.
- NEEDS national models submitted to Pan-European model (End 2006)
- First run of Pan-European model (March 2007)
- Harmonisation and modification of national models (until July 2007)
- Pan-European model on the basis of new submission of national models – implementation of Externalities and LCA – Scenario analysis
- Implementation of RES2020 enhancements in national models
- RES2020 Scenario Analyses (November 2007 – May 2008)
- Proposals for further studies

The starting point for the country models was very different. Some countries had many years of experience with MARKAL and TIMES that had been used for numerous national studies. Other countries, included Denmark, have started from scratch.

The strategy for the Danish model has been to rely very much on the common model structure and data and gradually introduce national data and assumptions. However, there is a long experience with model analyses using more detailed models in Denmark. The additional benefit for NEEDS-TIMES for Denmark is a model that is consistent and comparable with other European countries.

Table 4.4 shows a few selected model cases that were developed during this process. At the same time there was a continuous update of the model software with significant improvements of the tools. This process benefited not only for the other teams working with the NEEDS-TIMES model, but also other models using the software, e.g. EFDA-TIMES and TIAM.

Table 4.4. Extract of update log for the Danish NEEDS-TIMES model.

Case name	Date	TIMES	VEDA_FE	VEDA_BE	Regions	Comment
NEEDS_DKt36	20-02-07	v. 2.2.0	v. 3.0.12	v. 4.6.3	DK	Submitted for PanEur model.
NEEDS_DKt36d	17-04-07	v. 2.3.1	v. 3.111	v. 4.6.75	DK	Submitted templates.
NEEDS_DKu02	16-05-07	v. 2.3.1	v. 3.1125	v. 4.6.9	DK	Downloaded templates, revised.
NEEDS_DKt38	17-05-07	v. 2.3.5	v. 3.122	v. 4.6.9	DK	Demands as DKt36.
NEEDS_DKt47a	05-06-07	v. 2.3.5	v. 3.1255	v. 4.7.0	DK	SUBRES modified.
NEEDS_DKv13	15-07-07	v. 2.3.5	v. 3.1255	v. 4.7.0	DK	SUBRES/SuppXLS
NEEDS_DKv24	29-08-07	v. 2.3.7	v. 3.2.24	v. 4.7.12	DK	“Wind problem” solved.
NEEDS_DKw07	07-12-07	v. 2.5.0	v. 3.3.28	v. 4.7.21	DK	NEEDS/PanEur model
NEEDS_DKw20g	05-09-08	v. 2.5.0	v. 4.0.490	v. 4.7.70	DK	NEEDS PanEur model
RES_DK02i	06-09-08	v. 2.5.0	v. 4.0.490	v. 4.7.70	DK	RES2020 PanEur model, June 08
RES_DK03	19-11-08	v.2.9.0	v. 4.2.0	v. 4.7.72	DK	RES2020 PanEur model, Nov. 08

The continuous work with the model and software also led to modifications of the model structure and shift in the focus and emphasis on the various elements. In the early phase, most emphasis was devoted to the Base-Year templates, see Figure 4.2. Later the structure of constraints and harmonisation of these assumptions among countries became more important.

A few of the problems occurred during the process should be referred as examples that may have broader interest. The “wind problem” mentioned in Table 4.4 was due to a chance in the interpretation of the VEDA-FE base-year templates in version 3.1, when a share between zero and one in a formula was replaced by integers, leading to zero production from onshore and offshore wind turbines in Denmark from 2000. Also data problems, such as inconsistencies in demand forecasts has been traces by an update log more detailed than shown in Table 4.4.

The status of the development of the software and data at the time of writing (November 2008) can be summarised as follows:

- TIMES Many updates introducing new features, but very stable. OK
- VEDA_BE: Few updates, well consolidated software.OK.
- VEDA_FE: Many updates – demo model, usually OK. Real models may still lead to problems.
- Templates for particular models are still being considered for improvements. Input from different teams may lead to inconsistencies. Clarification of the structure and use of the software will be considered within ETSAP Annex XI.

4.7 Model data

On the ETSAP homepage ‘The model’ is described as “a set of data files (spreadsheets, databases, simple ASCII files), which fully describes the underlying energy system (technologies, commodities, resources and demands for energy services) in a format compatible with the associated model generator (MARKAL or TIMES) (…). Each set of files defines one model (perhaps consisting of a number of regional models) and is ‘owned’ by the developer(s)”, for example each national model of the NEEDS-TIMES Pan-European model.

4.7.1 Data sources

The key data source for the base year of the Pan-European model is Eurostat data for 2000, while the first versions of TIAM is using IEA statistics for 1999.

However, these international statistical sources are based on the same national reportings.

In Denmark the Danish Energy Agency reports annual statistics on energy supply and consumption of fuels to the IEA/Eurostat/UN. The file International Reporting contains information on 41 fuels and covers the period 1990-2006. The report is an Excel workbook containing energy balances for each fue plus capacities for renewables, public power plants and autoproducers of electricity, which is available from www.ens.dk Facts& Figures, International Reporting.

- Final Consumption is divided into Transport, Industry and Other Sectors.
- *Transport* is subdivided into road, rail, domestic navigation, pipeline transport and aviation (domestic and international)
- Industry is divided into 13 industrial sectors used in national account statistics:, emphasising large energy consuming sectors.
- *Other Sectors* are subdivided into “Commerce – Public Sector*, “Residential”, “Agriculture/Forestry”, “Fishing” and “Non-Specified”.

4.7.2 Reference Energy System and base year calibration

The reference energy system in with base-year data in NEEDS-TIMES is described in a set of five Excel workbooks, called Base Year templates, cf. Figure 4.2, each representing one of the following sectors:

- *Supply*: Reserves, resources, exploration and conversion, Country specific renewable potential and availability (onshore wind, offshore wind, geothermal, biomass, biogas, hydro)
- *Electricity:* Public electricity plants, CHP plants and heating plants
- *Residential and Commercial:* End use technologies (space heating, water heating, space cooling and others)
- *Industry:* Energy intensive industry (Iron and steel, aluminium copper ammonia and chlorine, cement, glass, lime, pulp and paper), other industries, autoproducer and boilers
- *Transport:* Different transport modes (cars, buses, motorcycles, trucks, passenger trains, freight trains), aviation and navigation

The reference energy system is described as a network of – mainly – energy flows (commodities) using PJ as the overall unit with technologies (processes) described by their initial capacities, efficiencies, availability and operation costs.

Materials flows whose production requires large amounts of energy or which are important for the production processes (e.g. scrap steel) are modelled as commodities in the model. Other materials are implicitly modelled as part of the variable costs and their related emissions are accounted for in the process emissions. The air emissions modelled are Carbon Dioxide (CO_2), Carbon Monoxide (CO), Methane (CH_4), Sulphur dioxide (SO_2), Nitrogen Oxides (NO_x), Nitrous Oxide (NO), Particulate (PM 2.5 and PM 10), Volatile Organic Compounds (VOC), Sulphur hexafluorides (SF_6) and Fluor Carbons (C_xF_y).

In addition the base-year templates are used for calibration of numerous parameters that are not found in the statistics, e.g. most efficiencies, power-to-heat ratios for CHP technologies, and disaggregation of flows and capacities that are modelled more detailes than found in the statistics.

4.7.3 Calibration for 2005:

So far no recalibration of the base-year templates have been made in the framework of the Pan-European model. While the effort of the national modelling teams for the model development in the first stage was devoted to the base-year templates. A full recalibration to 2005 and moving the stration year to 2005 would be time-consuming and become a major source of error. The current recommendation for the international multi-region models is that consistency with the 2005 statistics should be made by introducing a set of constraints. In scenario templates, cf. Figure 4.2.

5 The Danish energy system

This chapter summarises the description and key data used in the national report for the NEEDS Pan-European model. Updates to 2005 of the key statistical data are included to be used for calibration of RES2020-TIMES and later applications of the model. Together with the templates for the Pan-European model as released in October 2007 this chapter documents the Danish contribution to the first reported scenario study using the NEEDS-TIMES Pan-European model.

5.1 Supply

5.1.1 Fossil fuels (oil, gas, and coal)

Currently, Denmark is one of the few countries in the European Union that has a net export of oil and gas. There are no national resources of coal, but coal is imported in large quantities for use in the power sector.

At the time of the first oil crisis in 1973 more than 90 % of the Danish primary energy supply came from imported oil. Within a few years the oil crisis led to a considerable government intervention into the energy sector and to a swift response by the electricity supply industry, as it switched from oil to coal.

The Danish production of oil from the North Sea has developed from negligible amounts during the 1970s to the current level at 20 million m^3 since the late 1990s, half of which is exported. The gas production started in 1984. A few years before the build up of a national market was started on the basis of imported gas. The production increased until to the level at 7 billion m^3 1 from 1997 to 2003 and to 8-9 billion m^3 (350-400 PJ) from 2004 to 2007, of which about one-half is exported. Gas production is expected to fall, which may lead to import of gas.

Oil and gas reserves

By 2005 oil reserves in the Danish section of the North Sea was estimated at 268 million m^3. Thus a rough estimate of the reserves would be 18 years at the 2000-level. Gas reserves are estimated at 132 billion m^3. In 2004 the production was 9.2 billion m^3, which means that the current level can be maintained in 14 years.

The simplified assumption for the first approach to the Pan-European NEEDS model is that the reserves for oil are the 2000 production in 18 years and 17 years for gas. However, the energy strategy concludes that Denmark will remain self-sufficient with oil in the whole period until 2025. For gas new discoveries may reduce the dependency on imported gas.

Gas Storages

The two natural gas storage facilities in Denmark, Lille Thorup and Stenlille, have a total capacity of 1.7 thousand million m^3 (including the amount of working gas being 700 thousand million m^3).

Refineries

Three refineries were built in Denmark around 1960. However, until the mid-1990s Denmark was net importer of oil products in addition to import of crude oil. By 1996 the output from the three Danish refineries was about 20 % above the domestic demand. One of the refineries was closed down about 2000, and since the late 1990s the output of oil products from the Danish refineries has been similar to the Danish consumption, except for diesel and residual fuel oil, while Denmark has become a net exporter of crude oil, see Table 5.1

Table 5.1. Demand for oil product and refinery operation in Denmark 2000 and 2005.

	Domestic demand		Refineries	
	2000	2005	2000	2005
Input				
Crude Oil			271	346
Feedstocks			10	10
Output				
Refinery Gas	13	13	15	15
Liquified Petroleum Gas	4	3	8	7
Motor Spirit	87	82	100	84
Kerosenes - Jet Fuels	36	40	21	22
Naphtha	0	0	0	0
Diesel	149	160	138	136
Residual Fuel Oil	11	9	69	56
Non Energy	0	0	0	0
Other Petroleum Products	7	8	0	0
Total Oil Products	306	315	351	320

Sources: Eurostat

5.1.2 Electricity and heat

Most electricity is produced in thermal stations based on fossil fuels with a significant share of combined heat and power (CHP). Co-generation for district heating is an integrated activity of the electric utilities, while auto-producers of electricity and steam for industrial processes have never had a significant share of the market. From about 1980 all new power station have systematically been located to supply district heating systems with co-generated heat. In the 1980s nearly all new capacity was medium-sized extraction-condensing units for large-scale CHP; in the 1990s a significant share was small-scale gas-fired CHP units for decentralised district heating systems. Wind power has grown constantly during the 1990s and passed 10% of the electricity demand by 2000 on an annual basis.

During the last decade Denmark has been a net exporter of electricity to Norway and Sweden in years with normal precipitation. In 1996 the export was very large, due to a very ‘dry’ year. The base year for the NEEDS modelling, 2000, was a “wet year” in Norway and Sweden, and there was a modest net import of electricity to Denmark, 0.7 TWh. The year 2005 was similar; the import and export volumes were much larger – with net import at 1.4 TWh.

Table 5.2 shows the development of electricity generating capacity in categories that are suitable for the modelling. The main feature is the location to different type of district heating systems.

The largest group, extraction-condensing units are located at large urban district heating networks. They cover most of the supply of heat to these networks, when operating in back-pressure mode. The rest of their capacity will operate in condensing mode, similar to the condensing units. The latter operate nearly exclusively in condensing mode, but the also supply a small amount of heat to a limited heat market. All these units are flexible in their fuel supply, either immediately or after some rebuilding.

The group “back-pressure, decentral” are dimensioned for specific heat markets of very different sizes, and their operation depend on the heat demand. Their fuel flexibility is limited, most units use natural gas and some are using various forms of biomass. After 2000, none of the back-pressure units are using coal. Most of the larger units operate heat storages, which allow them to operate according to the electricity spot prices on the Nord Pool power exchange. However, before 2005 they were operating according to a time-dependent feed-in tariff.

Hydropower is only marginal in Denmark (11 MW), but the wind power capacity has increased very significantly during the last decade.

Table 5.2. Electricity capacity in Denmark by categories of generators

Generating Capacity	1980	1995	2000	2005
Coal, Back-pressure	19	133	89	0
Industrial CHP	90	160	398	558
Back-pressure, Decentral	258	1323	1799	1878
Back-pressure, Large DH systems	312	412	380	328
CHP, Extraction-condensing	3327	4488	3996	3953
Condensing	2619	3348	3074	2827
Hydro	8	10	10	11
Wind	1	617	2417	3136
Total	6634	10492	12164	12690

Source: Danish Energy Association. Electricity statistics and own calculations.

Coal was dominant in the early 1990s. It was reduced till about half in 2000. However, coal tends to be the marginal fuel to meet the increased demand for exports. In the dry year 2003 coal use was 91 PJ compared to 60-70 PJ in the years before and after. The use of natural gas for electricity increased during the 1990s from negligible amounts to about 30 PJ. After 2000 there has been a steady increase in the use of gas at 3-4 % annually. In the period 1995-2002 the annual use of orimulsion was 9-14 PJ.

The electricity demand composition is reflecting the structure of the economy and the policy with high taxation of households. Manufacturing industry is responsible for a much larger share of consumption than its share of value added, reflecting the high energy/electricity intensity for this sector compared to that of services.

The per capita consumption of electricity was around 6500 kWh in 2005. This is similar to most European countries, but much lower than in the other Nordic countries. There are very few large consumers.

Table 5.3 Electricity consumption in Denmark

Year	Total		Residential		Agriculture and horticulture		Manufacturing industries		Commerce and public service	
	TWh	%	TWh	%	TWh	%	TWh	%	TWh	%
1980	21.9	100	7.4	33.7	1.9	8.5	6.0	27.1	6.7	30.7
1995	31.5	100	9.6	30.4	2.6	8.4	9.6	30.5	9.7	30.7
2000	32.9	100	9.6	29.2	2.6	7.9	10.2	31.0	10.5	31.9
2005	33.6	100	9.8	29.3	2.5	7.5	9.8	29.1	11.5	34.1

Source: Danish Energy Association. Electricity statistics.

As shown in Table 5.3 the consumption by residential, manufacturing industries and commercial are now all around 30 % of the total. Over the last 25 years total consumption increased by about 54%. The relative share of residential and agriculture have been reduced, while the share of manufacturing industries and service has increased. The trends have been reversed somewhat in recent years as manufacturing has been reduced considerably from 2000 to 2005 and the increase in service has only been observed during the last 10 years.

District heating and natural gas grids

When natural gas was introduced in the early 1980s, district heating was well-established as a result of local initiatives over several decades. Early in the century district heating systems were established with supply of waste heat from city power stations. In the 1950s and 1960s many cities and towns invested in district heating systems, which were supplied by residual fuel oil from the newly established Danish refineries, and later also incineration of urban solid waste.

This infrastructure offered a very flexible response to the oil price shock in the 1970s. The central boilers could easily shift from oil to coal or gas, and many local district heating grids were interconnected into larger grids in order to exploit an excess production of heat from waste incineration during the summer, or connected to urban grids already supplied by CHP.

This development was further supported by the Heat Supply Act of 1979, which reserved the most densely built-up areas for district heating, while natural gas supply was planned in the less densely built-up areas. During the 1980s the existing district heating grids were expanded and interconnected, whenever possible, and all the large urban grids were connected to existing or new extraction-condensing power stations. This process was continued in the 1990s with smaller decentralised CHP units for the many district heating grids in towns and villages.

Heat supply to the district heating systems is now dominated by waste incineration and CHP. The total capacity of district heating boilers is 11.5 GW. Most of this capacity is inherited from the past and operate mostly as peak and reserve capacity to newer CHP plants. Heat storages are available in all the large-scale and most of the mid-sized district heating systems. The capacity of industrial autoproducers is small, but has been increasing during the last decade.

5.1.3 Renewable

Wind energy and biomass are the most significant renewable energy sources in Denmark, while the contributions of hydro power, solar and geothermal are negligible.

The total contribution of biomass in 2000 was 70 PJ or 8% of the primary energy requirement. The increase in the use of biomass since 1980 has been a part of the national energy policy. The contribution of biomass has further increased to 100 PJ in 2005.

Incineration of urban waste has a long tradition in the district heating sector, mainly for base-load heat supply, and most urban waste is used for energy.

The use of straw for energy purpose has been developed during the 1990s, mainly with the development of decentralised CHP, and this development has continued after 2000. This includes both combustion facilities for straw at CHP and district heating plants of different sizes as well as the infrastructure for recovery, storage and transport. By 2005 18 PJ or one-third of the available straw resources was used for energy purposes.

Wood chips and wood waste is also used in the district heating sector. Wood pellets have become a convenient replacement of oil for individual boilers, and a significant part of the consumption of wood pellets is imported.

The development of biogas has been much weaker, mainly due to technical and logistical difficulties. In 2005, there was a small production of biodiesel, which was exported.

Table 5.4. Biomass/Waste statistics.

	2000	2005	Comments
Straw	12	18	Transformation, agriculture etc.
Woodchips	3	7	Transformation
Firewood	12	18	Households
Wood pellets	3	3	Transformation and households
Wood Waste	7	7	Transformation and industry
Landfill Gas	1	1	Mostly transformation
Sludge Gas	1	1	Mostly transformation
Other Biogas	1	2	Mostly transformation
Biodiesel	0	3	Export
Municipal Waste Renewable	24	31	Transformation
Municipal Waste Non-Renewable	7	9	Transformation
Other	1	1	Including statistical differences
Production	71	100	
Imports	2	16	Woodchips, firewood, wood pellets
Total available	73	116	
Transformation sector	46	73	Straw, woodproducts, biogas
Final energy	27	40	Firewood, wood pellets and straw
Export	0	3	Biodiesel

Source: Danish Energy Agency. Statistics.

Geothermal Power, Solar Energy, and Heat Pumps are considered as energy commodities in the Danish energy statistics, but not in the energy balances from Statistics Denmark. The total primary production of geothermal in 2000 was 0.06 PJ, which was all used for district heating. The total contribution by solar was 0.3 PJ, 0.02 PJ was used for district heating and most of the rest was used in buildings. The contribution of heat pumps was 3.6 PJ in 2000 and 4.1 PJ in 2005, About two-thirds was used in single-family houses and one-third in agriculture and manufacturing industries.

The global potential of energy crops from agriculture is 102-142 Mtoe or 4270-5945 PJ. The Danish potential may be a few percents of this amount. As a first guess for the NEEDS-TIMES model the potential of each of the processes “Mining of bio energy crops (domestic)”, “Mining of bio rape seed (domestic)” is set to 50 PJ each (DG Research 2006).

5.2 Demand

In the energy matrices from the national accounts statistics, all energy demand refers to the branches in which the economic activity takes place. This includes transport fuels mainly for road transport. On the other hand, some fuels, e.g. gas/diesel oil, are split into road transport and other uses. In the following tables these fuels are included in the transport sector for comparison with Eurostat and the Danish energy statistics from the Danish Energy Agency.

5.2.1 Residential, Commercial and Agriculture

The demand for final energy from households, agriculture and the service sector is characterised by a shift in fuels, mainly from oil products to electricity and natural gas over the past twenty years, as shown in Table 5.5. Within the group other fuels district heating increased considerably, also replacing heating oil.

Table 5.5. Demand for final energy from households, agriculture and the service sector, 2000 and 2005.

	Eurostat VEDA 2000				*Eurostat VEDA 2005*			
	Electr.	Gas	Other	Total	Electr.	Gas	Other	Total
Households	36.9	27.5	108.5	172.9	37.6	29.5	116.5	183.7
Agriculture	7.0	3.4	30.9	41.3	6.9	2.2	26.8	36.0
Services	35.7	5.5	34.2	75.4	37.8	8.9	35.3	82.1

The NEEDS-TIMES model is based on a break-down of this statistics in the base-year into a large number of demand items and technologies. The statistical basis for this break-down is weak. In the initial model development many of the parameter assumptions have been common for several countries, while the thorough calibration of these parameters have had a low priority.

In *Residential* there are 11 end-uses (Space heating, Space Cooling, Water heating Cooking, Lighting, Refrigeration, Cloth washing, Cloth drying, Dish Washing, Other electric, Other energy), and the first three are differentiated by building categories (Single house – rural, Single house – urban, Multi Apartment). Similarly, the structure of the *Commercial* sector has nine end-uses (Space heating, Space cooling, Water heating, Cooking, Refrigeration, Lighting, Public Lighting, Other electric, Other energy uses), with the first three being differentiated by building categories (Small/Large). *Agriculture* is modelled as a single generic technology with a mix of fuels as input and an aggregated useful energy demand as output.

Residential

For the Danish model "Rural" is defined as single house without gas or district heating. The total number of dwellings are (1000s) 2415, the numbers of the three groups are 616, 825, and 964, respectively. The total floor area for dwellings is 281.9 mill. m^2. There is no statistics for dwellings with cooling facilities, and the number is negligible. An overall demolition rate is assumed at 0.15 per year.

Table 5.6. Residential electricity 2000

	PJ	
Household excl. heating	31.0	
Agricultural dwellings	1.8	
Electric heating	3.7	
Total	36.5	
End use description	PJ	*Fractional shares*
Lighting	6.3	17.3
Washing	5.4	14.8
Cooking	3.7	10.1
Cooling	8.3	22.8
Electronics	4.3	11.7
Heating	3.0	8.3
Miscellaneous	5.4	14.9
Total	36.5	99.9

Sources: Danish Electricity statistics, ADAM/EMMA, Elmodel-bolig

Water heating is always using the same technology as space heating. The share is assumed at 25 % of space heating plus water heating. The split of electricity demand into different end uses, mainly electric appliencies, which are modelled separately allows the model to consider technical progress in the assumptions for new technologies. The initial split for year 2000 is based on the assumptions in a national model for electricity use in households, “Elmodel Bolig”, which is used by the Danish Energy Agency, see Table 5.6 shows the split in 2000 among the various end uses.

Commercial

The total floor area for commercial and services is 90.5 mill. m^2. Small buildings are tentatively defined as 1000 m^2 and below. The split between small and large buildings is 23.8 and 66.7 million m^2, respectively.

Like residential an overall demolition rate is assumed at 0.15 per year. Most other parameters are identical with those of residential.

5.2.2 Industry

Table 5.7. Demand for final energy in industry 2000 and 2005

	Eurostat VEDA 2000				*Eurostat VEDA 2005*			
	Electr.	Gas	Other	Total	Electr.	Gas	Other	Total
Iron and steel industry	2.6	1.8	0.8	5.2	1.2	0.7	0.5	2.4
Nonferrous metal industry	0.3	0.1	0.2	0.5	0.3	0.1	0.1	0.6
Chemical industry	4.4	3.4	2.6	10.5	4.7	3.6	2.5	10.8
Non-metallic mineral products industry	3.3	6.3	18.3	27.8	3.3	5.4	17.1	25.8
Ore extraction (except fuels) industry	0.3	0.0	2.4	2.8	0.3	0.9	2.2	3.4
Food, drink and tobacco industry	8.1	11.5	11.3	30.9	8.6	8.2	10.1	26.9
Textile, leather and clothing industry	0.8	1.2	0.3	2.3	0.8	1.0	0.4	2.2
Paper and printing industry	2.7	2.1	1.0	5.7	3.2	2.6	1.2	7.0
Engineering and other metal industry	6.4	4.2	4.5	15.2	6.7	4.7	4.5	15.9
Other non-classified industries	7.1	2.4	13.4	22.9	7.9	2.8	12.9	23.5
Total Industry	36.0	33.0	54.7	123.7	36.9	30.0	51.6	118.5

Table 5.7 shows the demand for final energy from the industrial branches as specified in NEEDS-TIMES.

The development over the past twenty years is based on the energy matrices, which are part of the national account statistics. The statistics is divided into some 60 branches covering manufacturing industry and construction. Over the past twenty years before 2000, there was a moderate increase in total final energy demand in most industrial branches and a significant shift from ‘other fuels’ to gas and electricity. The three branches that dominate the energy demand are ‘Non-metallic mineral products industry’, ‘Food, drink and tobacco industry’ and ‘other non-classified industries’.

Iron and steel

By 2000 there was a single recycling steel plant using electric arc furnace and gas reheating in the rolling mill. Excess heat has been delivered to district heating. The plant was closed down in 2002, but has operated partly in periods from 2002 to 2005.

Non-ferrous metals

No national processing of aluminium or copper can be identified in national statistics. Data are calibrated automatically using Eurostat information in ‘other non-ferrous metals. The total energy demand is small, about 0.5 PJ.

Chemical industry

The Danish production of ammonia was closed down in 1982, and no chorine production is identified in statistics. The total energy demand from chemical industry is 11 PJ.

Nonmetallic mineral products industry

The total energy demand is 28 PJ, of which 9 PJ is from cement, 12 PJ from hollow glass, and 6 PJ from Other Non Metallic Minerals.

There is a single cement plant using ‘dry process production’. Since 1982 there has been no production of plane glass in Denmark. The demands for cement and hollow glass are calibrated from the energy demand. There is no energy demand from lime, and, thus lime demand is set to zero.

Paper industry

In Denmark this is mainly printing industry, which is interpreted as the model branch ‘high quality paper industry’.

Other industries

Other industries. ‘Food, drink and tobacco industry’ and ‘other non-classified industries’. Total demand is 65 PJ.

5.2.3 Transport

The transport energy demand in dominated by road transport, which increased by 50 % over the past 20 years before 2000.

Table 5.8. Transport energy demand 2000 and 2005.

	Eurostat VEDA 2000				*Eurostat VEDA 2005*			
	Electr.	Gas	Other	Total	Electr.	Gas	Other	Total
Rail	1.3	0.0	3.1	4.3	1.4	0.0	3.1	4.4
Road	0.0	0.0	154.1	154.1	0.0	0.0	170.2	170.2
Air	0.0	0.0	34.4	34.4	0.0	0.0	39.6	39.6
Inland navigation	0.0	0.0	4.8	4.8	0.0	0.0	5.7	5.7
Total	1.3	0.0	196.4	197.6	1.4	0.0	218.6	220.0

There is an inconsistence in the transport sector for air transport and inland navigation between Eurostat, which is identical with the energy statistics from the Danish Energy Agency, and the energy matrices from the national account statistics. The branch “Water Transport” (part of NACE I) in the national account statistics is based on accounts statistics from shipping companies, including those operating ferries between Denmark and the neighbouring countries. Only activities on Danish economic area are included in the statistics. In spite of this the consumption of diesel and light fuel oil is 12.1 PJ in 2000, compared to 4.8 PJ in the energy statistics and Eurostat.

No additional assumptions were made for transport in the first approach to the Pan-European model, except that lifetime of transport equipment in general was set to 20 years.

5.2.4 Non Energy Uses

For 2000 Eurostat registers 11.7 PJ demand in the group ‘White & Industrial Spirit, Lubricants, Bitumen’ outside the chemical industry. This is mainly for lubrication and road surfacing. The demand for non-energy use has declined over the past twenty years. The figure was 11.5 PJ in 2005.

5.3 Air emissions

When fully implemented NEEDS-TIMES calculates all emissions that are considered in the Kyoto Protocol as well as SO_2, NO_x, CO and non-methane VOC. Table 5.9 shows the total emissions for Denmark from the Eurostat database and emission from the power sector (Eurostat sector 1_A_1A). Some of these emissions – in particular SO2 – were significantly reduced before 2000. The CO_2 emissions from the electricity sector are very dependent on the electricity trade, which varies with the precipitation and, thus, the availability of hydro power in Norway and Sweden.

Table 5.9. Emissions (without correction for electricity import)

	Total Emissions			Electricity and heat		
	1995	2000	2005	1995	2000	2005
Sulphur dioxide (SO2)	136	29	22	103	12	8
Nitrogen Oxides (NOx)	264	207	186	83	43	39
Carbon Monoxide (CO)	712	559	611	10	11	11
Volatile Organic Compounds (NMVOC)	158	131	118	3	4	4
Methane (CH4)	284	280	268	21	27	26
Nitrous Oxide (NO)	30	27	22	0	0	0
Carbon Dioxide (CO2)	60523	53068	50306	29828	22677	19603
Hydrofluorocarbons (HFC - CO2 eq.)	218	605	805			
Perfluorocarbons (PFC - CO2 eq.)	1	18	14			
Sulphur hexafluorides (SF6 - CO2 eq.)	107	59	22			
Particulate (PM 2.5 and PM 10)		36	39		0.8	0.6
Particulate (PM 2.5 and PM 10)		24	28		0.7	0.5

Source: Eurostat

5.4 Taxes

Table 5.10. Energy taxes (EUR-2000/GJ)

	2000			2005		
Excise taxes.	CO2	Energy	Sulphur	CO2	Energy	Sulphur
Transport						
Diesel	0.92	10.61		0.83	9.58	
Unleaded petrol	0.91	16.01		0.83	14.46	
Other energy use						
Gas oil 0,2% S	0.92	7.07	0.13	0.83	6.38	0.12
Fuel oil 1%	0.97	7.03	0.67	0.87	6.35	0.61
Natural gas	0.68	7.01		0.62	6.33	
Electricity for heating	3.28	19.38		2.96	17.50	
Electricity, other	3.28	21.88		2.96	19.76	
Waste for CHP	0.00	3.58	0.12	0.00	3.23	0.11
Waste for district heating	0.00	4.22	0.12	0.00	3.81	0.11
Heat from waste	0.00	1.73	0.00	0.00	1.56	0.00
Straw	0.00	0.00	0.22	0.00	0.00	0.20
Wood pellets	0.00	0.00	0.31	0.00	0.00	0.28

Source: Danish Energy Agency and own calculations.
Note: The Sulphur tax for transport fuel is similar to other uses, but given as 20 DKK per kg S.
Exchange rates 7.454 DKK-2000/EUR-2000 and 8.253 DKK-2005/EUR-2000.

Energy taxes were introduced in the early 1980s and increased in 1986 following the decrease in international oil prices. Fuels used for other purposes than power generation are taxed directly, whereas electricity is taxed with the consumer. To comply with the general tax policy, energy taxes have been constant in nominal terms since 2001. Table 5.10 shows the most important tax rates as calculated in constant EUR 2000 as used in the Pan-European model.

6 Results from the NEEDS Pan-European model

This chapter summarises the assumptions and resulte for the first Danish reference case for the NEEDS Pan-European model and the aggregated results of the two scenarios for the Pan-European model that were presented on the basis of the release of the model for all 29 countries in October 2007.

6.1 First Danish Reference Case for the Pan-European model

The Danish Energy Strategy to 2025 assumes investment based on market conditions, which may lead to lower reserve capacity and lover security of supply. The strategy asks for analyses of the electricity system with less reserve, but does not contain such analyses.

In additional scenarios, the Danish Energy Strategy to 2025 assumes crude oil prices between 20 and 50 $ per barrel. The scenarios combine high and low crude oil prices and high and low prices for CO_2 quotas.

In building the model for the BAU scenario the number should be reduced to a minimum in order to have results that are created by the optimisation. In addition to constraints that express resource and infrastructure limitation or some well-established policies, a number of constraints may be necessary to overcome model limitations.

Forecasts for import prices for crude oil, oil products and natural gas follow the general forecast for all countries. These forecasts were modified and updated during the development of the first version of the Pan-European model, following the latest European forecasts by the GEM-E3 model. Export prices for the same fuels are 1 % lower than import prices. Delivery costs are specific for technologies and fuel types, and should be considered as national specific. Crude oil prices in the scenarios are increasing from 6.51 €-2000 per GJ in 2005 to 7.53 € in 2050, equivalent to 47 and 53 $-2005 per barrel. These prices are between those used by IEA for ETP 2006 and 2008.

The Danish model was developed as one of 29 harmonised models for European countries. The primary aim at this stage of development is to select assumptions that were able to provide reasonable forecast results, which may be studied in further details in order to evaluate and improve the large number of parameter assumptions. In many cases the best choice of parameter assumptions are values used in other national models, in particular those that were used as basis for development of several national models. For this reason German data were preferred for parameter assumptions for the development of the Danish model.

6.1.1 Summary of main constraints

Initially these constraints reflected the structure of the energy system and resource limits, e.g. the capacities of the district heating and gas grids and the available biomass resources and waste for incineration.

Additional constraints were added during the stepwise development of the reference forecasts, e.g. minimum values for electricity and gas in sectors where no particular conversion processes were specified, e.g. gas and electricity consumption in “other industries”, which would otherwise be replaced by cheaper fuels.

Most of these constraints should be replaced by more detailed infrastructure constraints during the further development of the model.

6.1.2 Electricity

Electricity system issues

No new large fossil fuelled units are assumed before 2010.

The Base Case of the Energy Strategy 2025 assumes that 27 % of the Danish electricity generation in 2025 is covered by wind. This increase is modest compared to the current 20 %. It is also assumed that Denmark will be net exporter of electricity in the whole period. At an annual basis the Danish demand will be covered by wind power and CHP generated electricity. However, import and export will be essential for the operation of the Danish electricity system.

These features can be modelled in TIMES only by setting appropriate constraints and parameters, which need to be developed partly by trial and error. In the first version wind power capacity was exogenous following the assumptions of the Danish Energy Strategy 2025.

Retirement profile

In the first approach (May 2006) all condensing thermal plants (electricity-only technologies) is reduced from 100% in 2000, (2.59 GW) to 75 % in 2005 50% in 2010 25% in 2015 and zero by 2020. These plants are mainly older plants located away from district heating networks.

Retirement of the newer CHP units – both central extraction-condensing units and decentral back-pressure – units follow a similar path, but 5 years later. The total capacity in 2000 was 6.41. GW. For wind power the capacity in 2000, 2.8 GW, will be retired during a ten-year period from 2010 to 2020.

This retirement profile is consistent with the main assumption in the Danish Energy Strategy to 2025. The current electricity spot price on the Nord Pool electricity exchange is too low to justify investment in new capacity. It is assumed that the spot price will increase gradually until about 2015, as the existing reserve capacity will be phased out. The higher spot price will make investment in new generating capacity attractive.

The retirement profile was not modified in the development process. However, the Energy Strategy and more recent planning efforts in Denmark includes a detailed decommissioning assumption. These assumptions should be implemented into the Danish model at a later stage,

Wind power

According to Eurostat the wind power capacity in 2000 was 2.8 GW. In recent years many older wind turbines have been scrapped and replaced by fewer, larger turbines. In addition several pilot projects for off-shore wind power has been developed. According to Danish Energy Strategy to 2025 off-shore wind farms could be commercially interesting after 2011, depending of the framework conditions. The range of the assumed off-shore development in the period 2011 to 2030 is wide: between 800 MW and 4200 MW new off-shore capacity.

The energy strategy (Base Case) assumes 400 MW offshore wind power until 2010 (from about 2002) and net increase of onshore capacity at 173 MW. By the end of 2000 the total wind power capacity was 2972 MW, of which 210 MW was off shore. By the end of 2005 these figures were 3135 MW and 399 MW, respectively. For the Pan-European model it can be assumed that additional 400 additional offshore capacity will be installed until 2010. This is consistent with the target in the energy planning since the mid-1990s, and tendering for this capacity was agreed by a large majority in Parliament in 2004 (www.windpower.org).

Thus, the minimum installed wind capacity by 2010 is set 3550 MW, of which 800 MW will be off shore. This will be the minimum capacity for the rest of the period until 2050 in the BAU scenario. The maximum capacity is set at 8000 MW, of which 4000 MW will be offshore.

District heating and gas grids

Investment in new district heating and gas grid cannot be optimised without a very detailed representation of the geography in the model. This means that the grid development must be exogenous. Most areas suitable for district heating and gas were developed during the 1980s and 1990s, and further development of district heating may be limited. There is still a potential for adding customers to existing grids, but unit consumption is likely to decrease because of better insulation. New single-family houses may be too energy efficient to justify major investments in water-based heat distribution systems.

6.1.3 Resource and infrastructure constraints

As mentioned in Section 5.1.1 oil and gas resources in the North Sea will be exhausted within the modelling period. The highest production level will be about present. A constraint that limits the production to the present level will be the first approach in for the model. The next step may be to implement a production profile in accordance with the most recent studies from the Danish Energy Agency.

Outside the electricity and district heating sector constraints on the use of some fuels will be necessary, either assuming no investment in some technology processes or no use of some fuel commodities, e.g. coal outside the electricity sector.

6.1.4 Energy demand

The demand forecasts in the NEEDS Pan-European model is based on GEM-E3 forecasts.

These assumptions includes forecasts of demand drivers, assumptions on income elasticities, price forecasts and emission coefficients. The method and assumptions are described by Kanudia and van Regemorter (2007).

6.1.5 Results of the base case of the Pan-European model till 2050

The development of the Pan-European model within the NEEDS project was finished in the Autumn of 2007 and the aggregated results for all countries have been presented at several workshops afterwards.

This means that the Danish model is ‘freezed’. The results and assumptions can be studied in details and compared with other models, but any modification and improvement should be made with reference to the ‘freezed’ model version. The following figures are selected from those that were developed for the presentation of the Pan-European model.

Electricity generation

Figure 6.1 shows the net electricity generation in the base case till 2050. The increase in wind is the result of the planned investment and not of the optimisation. In the shorter term until 2015 the role of coal will be reduced and gas gains a larger share. This is partly a result of decommissioning of older – mainly coal-fired capacity. After 2015, most new investment will be in new coal-fired technology, because the emissions of CO2 are not constrained in the base case. These results are reflected very directly in Figure 6.2, showing the fuel input.

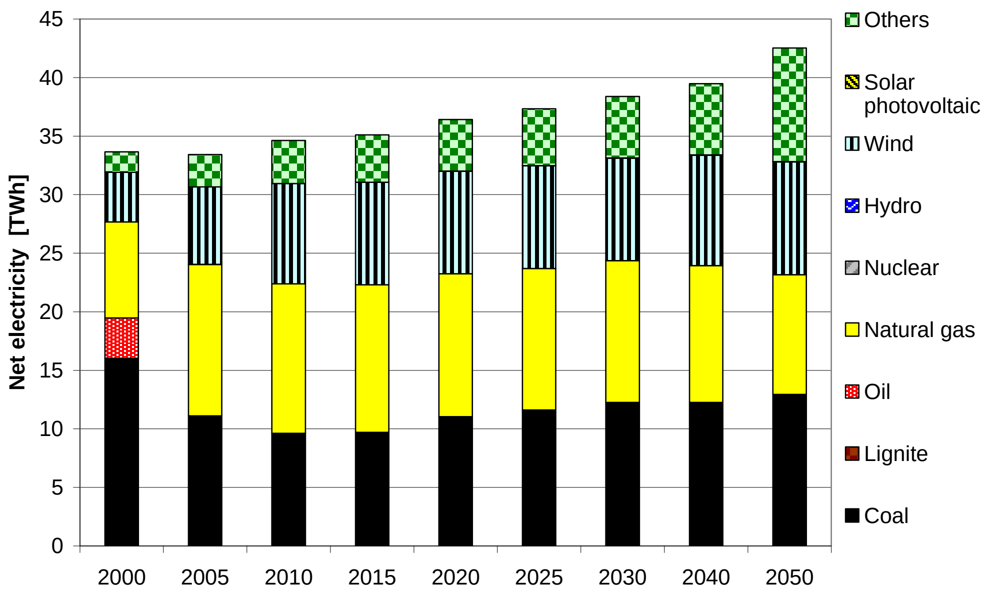


Figure 6.1. Pan-European model October 2007, BAU. Net electricity generation, Denmark.

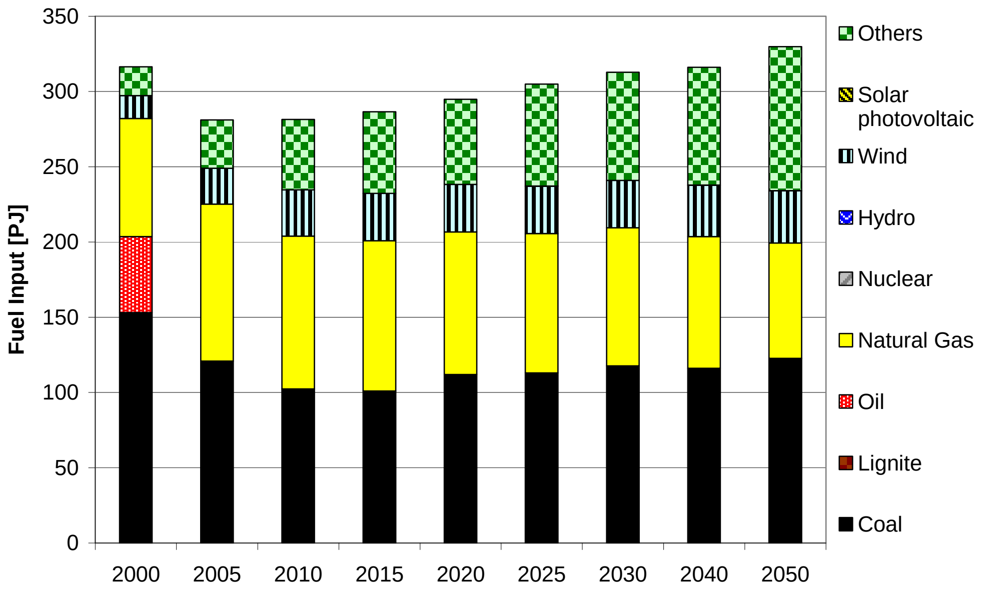


Figure 6.2. Pan-European model October 2007, BAU. Fuel input for electricity generation, Denmark.

The relative small electricity generation by oil disappears in the optimisation from 2005. This indicates that the technical constraints may not be sufficiently detailed. Danish coal-fired plants normally use oil for start up, but not as much as shown for 2000. An appropriate constraint for the share of oil should be calculated and tested for a later version of the model. In Figure 6.3 showing the development in capacities, the oil-fired capacity is phased out. These units are mainly kept as reserves with very few operation hours, and there is no new investment in oil-fired units.

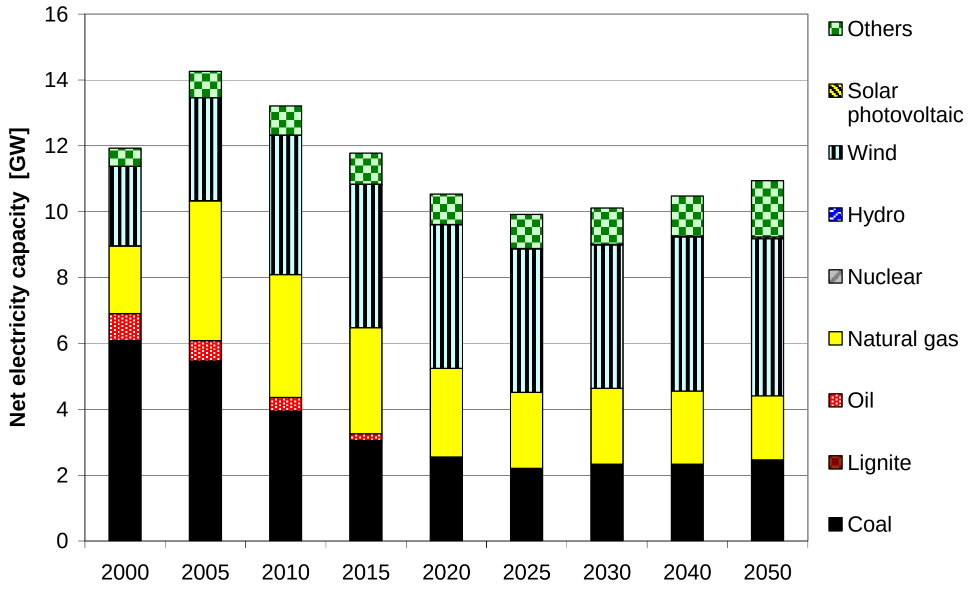


Figure 6.3. Pan-European model October 2007, BAU. Net electricity capacity, Denmark

Final energy demand

The current model specification tends to select coal, biomass and other renewables for the end-use sectors. Some resource-limited fuels, e.g. geothermal, were constrained by their resource availability already in the initial development of the model. In the later development, coal was excluded from the residential, commercial and agricultural sectors, and a lower limit was set for natural gas to avoid an unlikely phasing out of gas, which would be due mainly to the relative prices currently used in the model as well as more detailed infrastructure constraints.

For transport only constraints used in several national models were used. The current results show that hydrogen, methanol and natural gas is chosen by the model after 2020.

Air Emissions

Figure 6.4 shows the unconstrained development of CO_2 emissions as calculated from the current result of the optimisation.

6.1.6 Scenarios of special significance to the national system

For Denmark electricity trade will have particular impact on the electricity system. It means that scenarios focusing on electricity prices and their distribution among time-slices and the treatment of the stochastics of hydro power will be of particular interest. Addressing these issues may depend on an analysis of preliminary results from the Pan-European model.

These scenarios shall be co-ordinated with the neighbouring countries, focusing on hydro power in Norway and Sweden and wind power in Germany – in particular the northern parts of Germany.

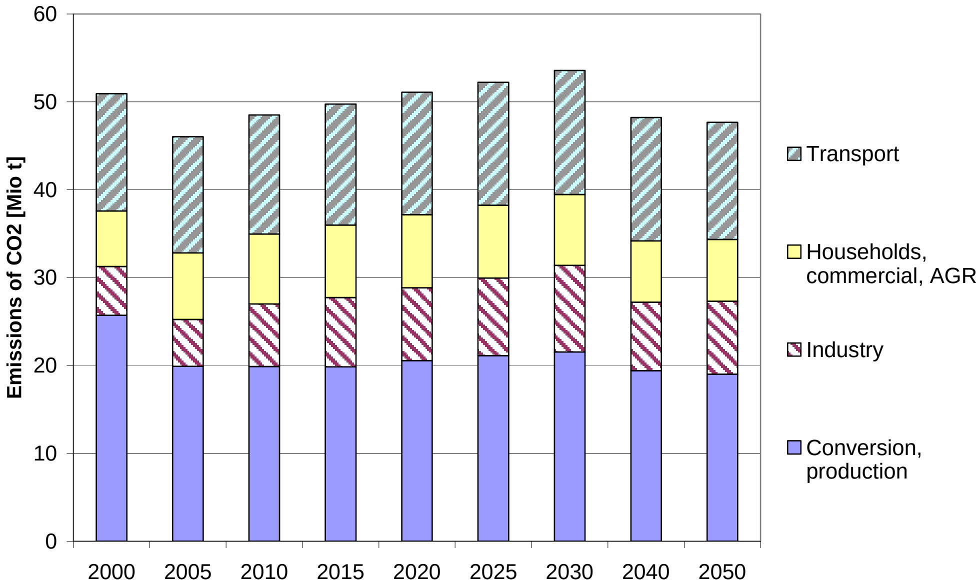


Figure 6.4. Pan-European model October 2007, BAU CO_2 emissions, Denmark

6.2 First Scenario results of the Pan-European Model to 2050

The first results of the NEEDS Pan-European model to 2050 were presented at a project meeting of the NEEDS Research Stream 2a in October 2007. These results are based on a common optimisation of the national models for the 29 countries, considering two scenarios:

– Specification of the Baseline case (BAU)

– Post-Kyoto climate policy to stabilize CO2e concentrations at 440 ppm (CO_2)

The results of these two scenarios have been presented at several conferences and workshops, including the CEEH workshop at Risø DTU in February 2008 and the IEW-ETSAP workshop in Paris June 2008. These scenarios are also described in the ETSAP Annex X report.

Figure 6.5 compares CO_2 emissions in the two scenarios. In the business-as-usual scenario without restrictions on CO_2 emissions, the total emissions from the 29 countries would increase from 3800 million ton in 2000 to more than 5000 million ton 2050. This fairly moderate increase in CO_2 emissions will be the result of increased demand for energy and new and more efficient technologies. An important assumption for this result is the real discount rate, which is set at 4 % p.a. in compliance with other recent EU studies focusing of long-term technology development, e.g. SAPIENT. With the very severe restriction on CO_2 emissions, it was possible for this optimisation model to produce a consistent and mathematically feasible result, which has been reported and may be studied in details as a reference for future studies using the same type of models or different models for the European countries. The restrictions on emission are introduced gradually from 2010, and it follows from Figure 6.5 that CO_2 emissions are reduced in all sectors, but not at the same time. Significant reduction will be seen first in the conversion sector and last in the transport sector. This is consistent with traditional expectations.

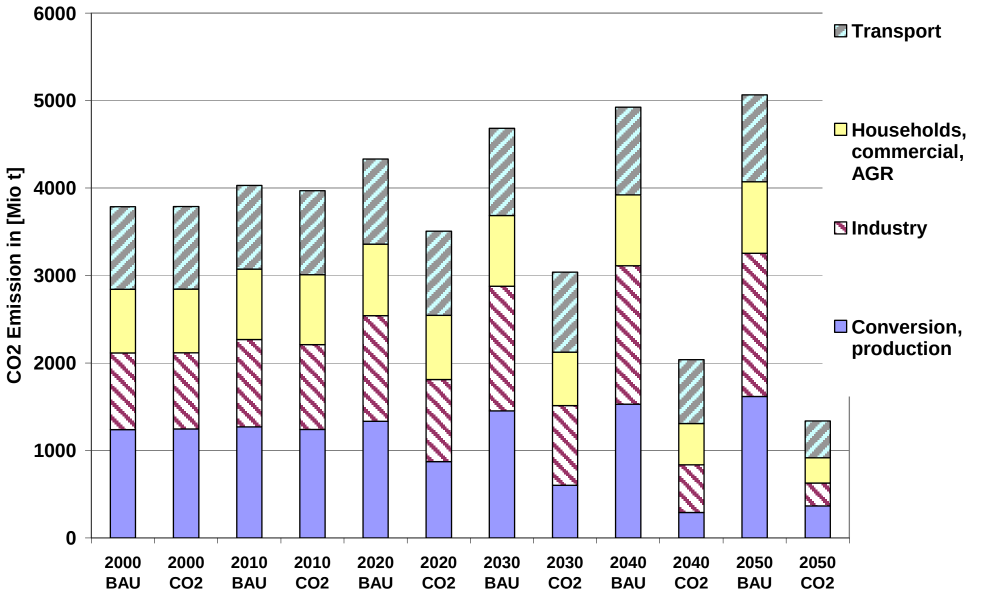


Figure 6.5. First results of the Pan-European Model: CO_2 emissions.

The Pan-European CO_2 scenario goes further than IEA's ETP 2008, which were the first time that an IEA has explored a 50 % reduction scenario.

The following figures explain how this result could be achieved. As shown in Figure 6.6. total final energy consumption will increase in both scenarios until 2040, and there will be a small decrease in the CO_2 scenario in the last decade. Electricity use will increase in both scenarios, but most in the CO_2 scenario, while direct use of gas will decrease in the CO_2 scenario. Obviously, renewables become more important in the CO_2 scenario.

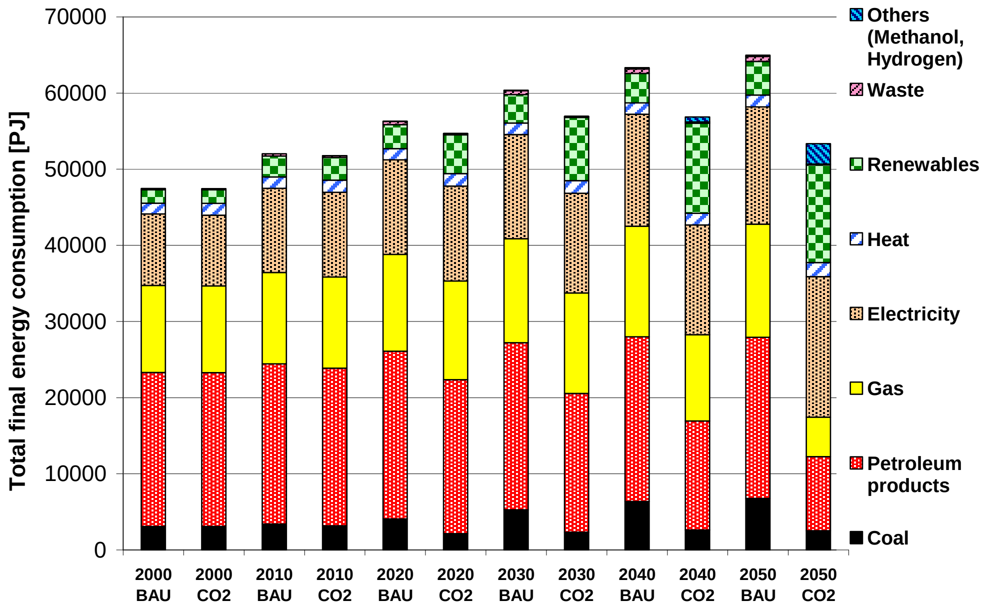


Figure 6.6. First results of the Pan-European Model: Total final energy consumption.

The developments shown in Figure 6.7 for industry and Figure 6.8 for the residential and commercial sector follow the same pattern.

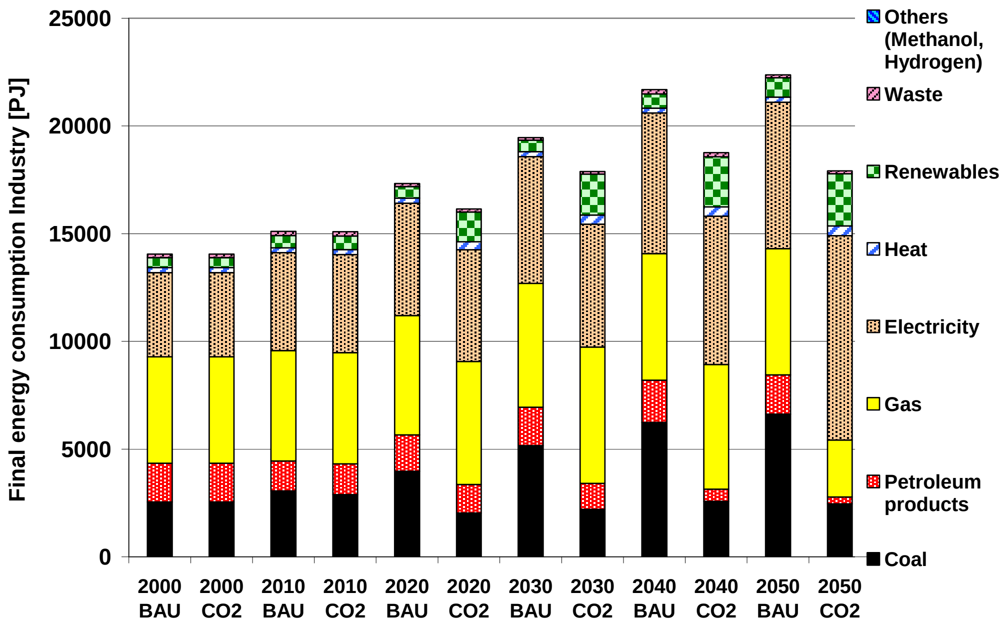


Figure 6.7. First results of the Pan-European Model: Final energy consumption in industry.

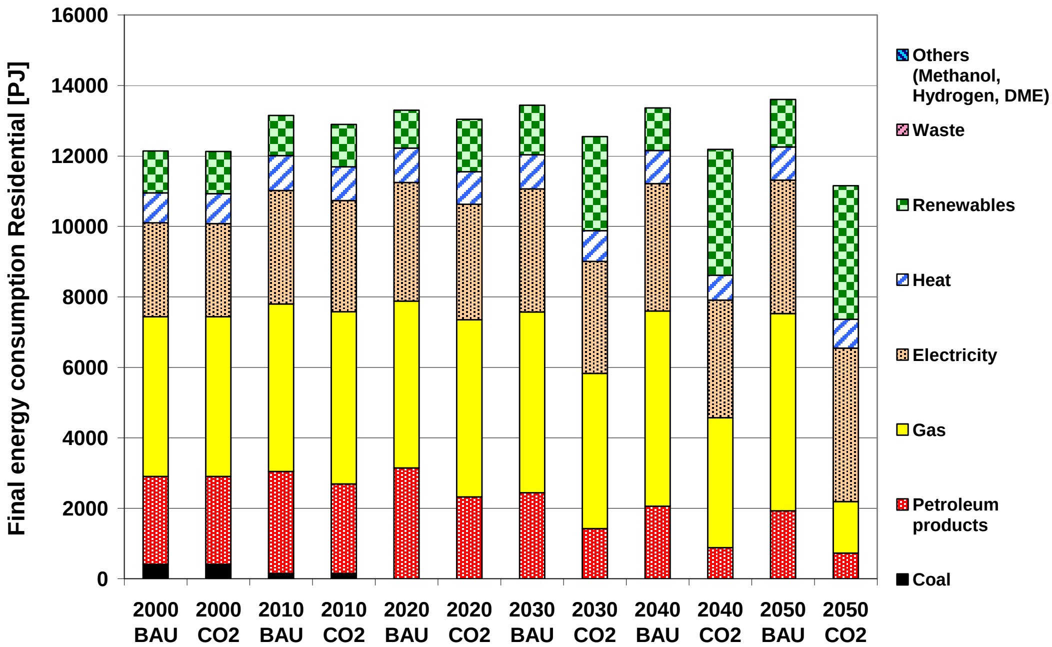


Figure 6.8. First results of the Pan-European Model: Final energy consumption, residential

The development of final energy in transport in Figure 6.9 illustrates the tradition for very conservative assumptions for the technology development in the transport sector. Renewables in the form of biomass are considered as well as new fuels as methanol and hydrogen, but electric cars have not been considered so far.

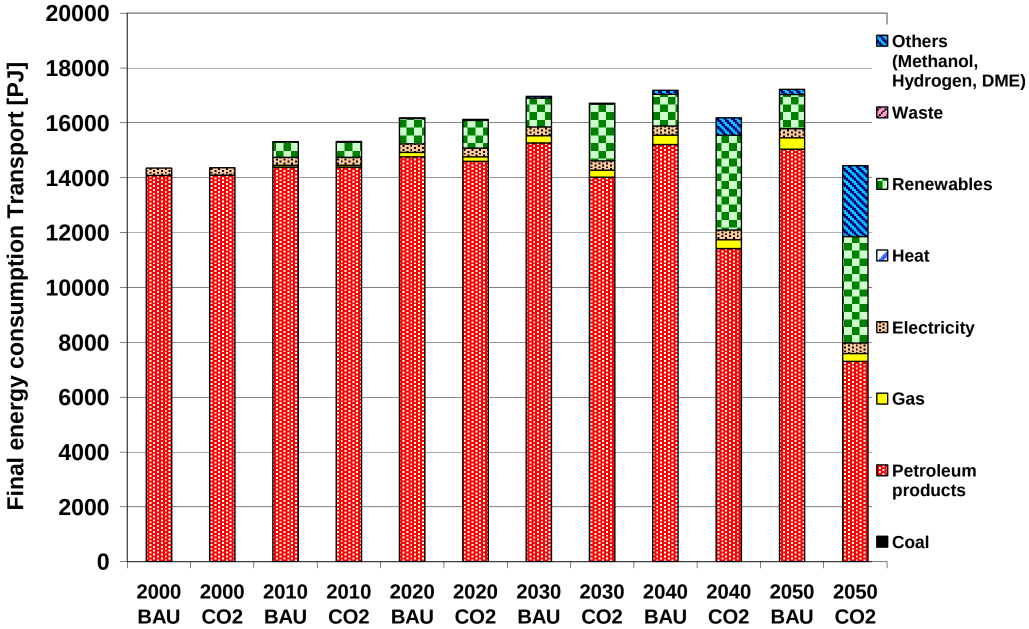


Figure 6.9. First results of the Pan-European Model: Final energy consumption in transport

The fuel mix for electricity in Figure 6.10 explains part of the previous results. There is no single dominant technology in the CO_2 scenario. Nuclear and wind becomes slightly more important in the CO_2 scenario, but the main difference is natural gas, which will be used in combined cycle gas turbines with carbon capture and storage, as illustrated in Figure 6.11, which shows the installed new capacity for electricity generation.

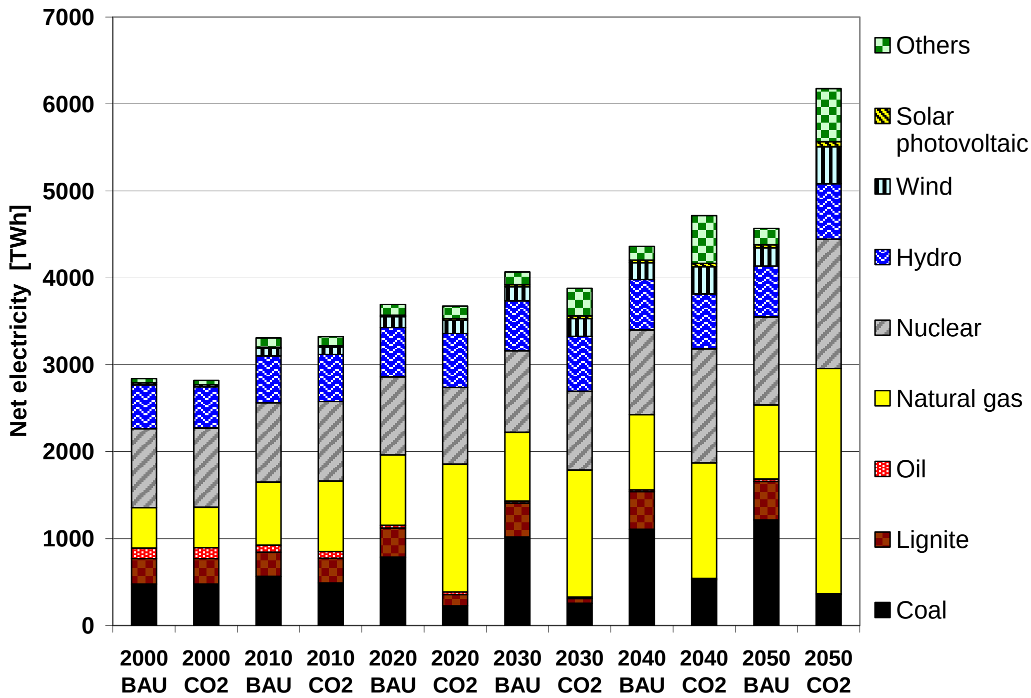


Figure 6.10. First results of the Pan-European Model: Net electricity generation.

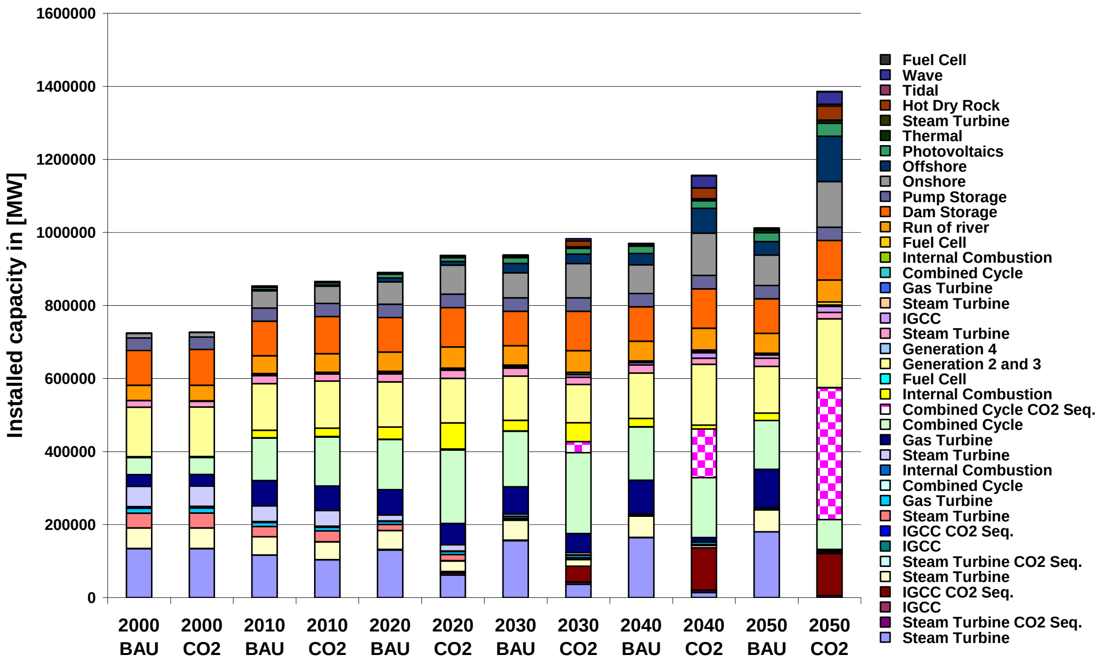


Figure 6.11. First results of the Pan-European Model: Installed electricity capacity.

Figure 6.12 shows the moderate difference in primary energy use between the two scenarios. In the CO_2 scenario there will be less coal and oil and more nuclear and renewable, but nearly the same amount of gas as in the business-as-usual scenario,

In summary, natural gas combined cycle with CCS for electricity generation is a key technology for electricity generation. This does not increase the total demand for gas, because gas as final energy in other sectors is replaced by electricity and renewables.

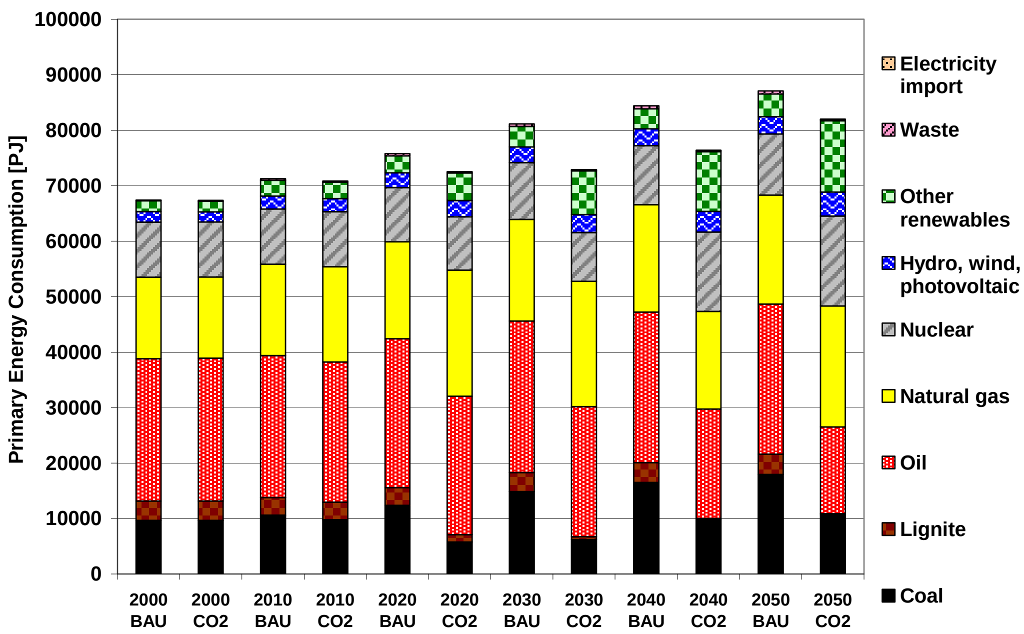


Figure 6.12. First results of the Pan-European Model:Primary energy consumption.

7 Future work

The development of a Danish model using the ETSAP tools is still ongoing. The further development of the model will benefit from a wide range of international activities and national, both within the framework of ETSAP and outside, in particular Danish, Nordic and European research. These modelling activities are of different scopes and time horizons.

7.1 Ongoing International studies

Modelling studies covering several regions and nations has been the main driver of the development of the ETSAP tools in the past and will remain so in the future. Important spin-offs of these activities is the development of modelling tools and insight that is also available for national and local model studies.

7.1.1 Time horizon 2100

The two global models TIAM and EFDA-TIMES will be developed further, TIAM as the flagship under ETSAP Annex XI focusing on climate change within the framework of IEA activities, and EFDA-TIMES with its particular focus on fusion energy and the range of complementary and competing technologies. These two models have a common origin, but they differ in scope, and their further developments will take different directions. Still their common feature will be the VEDA user interface. The TIAM model has a facility for “country-out-region-in”, which allows the development of a Danish model that may run together with the Western European region and the remaining 14 region in the global model.

7.1.2 Time horizon until 2050

The immediate next application of the Pan-European model is within the EU RES2020 project under Intelligent Energy Europe. This project will focus of the following enhancements of the Pan-European model developed under the NEEDS project:

– Renewable electricity generation, including wind and distributed electricity generation

– Biomass for electricity and heat

As a result of the experience with the model development so far, the Pan-European model, which has been taken over from NEEDS will be run centrally as a multi-regional model. This will allow a more efficient calibration of 2005 data that are now available from Eurostat as well of enhancement and restructuring of the model that is co-ordinated with the improvements of the VEDA Front End software. The next two new versions of the Pan-European model has been distributed to the teams responsible for the national models were distributed by June and November 2008. Comparing these results with the first version of the Pan-European model is a very important step in the further development and improvement of the model.

Another EU project that will use the NEEDS-TIMES model is REACCESS (Risk of Energy Availability: Common Corridors for Europe Supply Security) – started in February 2008. Participation from Italy, Kazakhstan, Spain, Germany, France, Russia, Norway, Greece, Austria and Finland. Focusing on energy import to the EU, security of supply and environmental policies.

Although the time horizon for RES2020 is 2025, the current Pan-European model is able to explore the full time horizon until 2050. This may be useful for other studies to be started in the near future that may focus on particular technologies, e.g. carbon capture and sequestration, which is well represented in the current model.

7.1.3 The EU Coordination Action FENCO ERA

FENCO-ERA is a Coordination Action (CA) within the EU 6th Framework Programme. The overall aim of is to network the national and regional R&D activities in the field of fossil energy conversion and carbon capture and storage (CCS) technologies. Among the objectives of the network is to further develop economic modelling and to explore the economic potential of full deployment of CCS technologies within the portfolio of climate change mitigation options. Denmark, as represented by the electricity and gas system operator Energinet.dk, is among the 11 countries participating in FENCO-ERA.

A consortium of institutes with expertise in using the ETSAP modelling tools from all countries around the North Sea, submitted a proposal in the Autumn of 2008 concerning the use of existing national models to evaluate projects for CO_2 storages in the North Sea region and development of a common regional model.

7.2 National studies

As follows from the description of ETSAP activities in the previous chapter numerous studies focusing on national issues have been carried out using the ETSAP tools and contributed to their further development. Before Annex X the Danish activity has been limited. As a part of this project on Danish participation in ETSAP Annex X the work on the Danish model development within the European project have been presented for the Danish modelling community on workshops in preparation of the ETSAP semi-annual meeting and on the Risø DTU website. These activities shall continue under the new project on participation in ETSAP Annex XI. This project aims at enabling Danish model studies, which are consistent with European and global models, e.g. participation in analyses following decisions during COP 15 in Copenhagen in December 2009.

7.2.1 CEEH – Centre of Energy Environment and Health

The Centre for Energy, Environment and Health (CEEH) is funded by the Danish Council for Strategic Research, and run over 5 years from January 2007. CEEH is a collaboration between scientists from different research fields, with the mission to develop a system to support planning of future energy systems in Denmark, where both direct and indirect costs related to environment, climate and health are considered. The centre will work with a number of different realistic scenarios for the quantity and type of the future energy production and associated emissions. These objectives are similar to those of the NEEDS project, which means that the centre can benefit significant from participating in ETSAP model activities.

– The main outcome of the centre is an integrated regional model chain consisting of air pollution models, models for optimisation of energy systems and including components for air pollution chemistry and dispersion down to urban and sub-urban scales, and model components of the impacts on public health and the external environment.

– The system will be designed to minimize the grand costs of Danish energy system. Boundary conditions will be obtained from a global and regional energy system model and from a global air pollution model.

– To create global energy and emission scenarios, supplying boundary conditions to the regional and local models, we focus on the MARKAL family of models and relevant projects (such as NEEDS).

The scientific work of the centre will be the basis for 6 PhD projects, which will be started in 2008.

Starting Mid-2008 Erika Zvingilaite is working on the energy demand modelling with focus on local externalities. The project is motivated by a need for a better modelling of the energy demand in energy system models. Often energy demand is exogenous to models used for optimising future energy systems, and at the same time large potentials for more efficient and flexible use of energy exists. The main objective of the PhD project is to develop an energy demand model covering Denmark; Norway; Sweden; Finland; and Germany. The model should describe all final energy demands in all the countries and all sectors. This work will in particular benefit from participation in some of the ETSAP workshops as well as collaboration ETSAP partners.

Other PhD projects within CEEH focuses on atmospheric and air pollution modelling at the Danish Meteorological Institute and the National Environmental research Institute

7.2.2 Post doc – Evaluating sustainability of bioenergy production using ecological and economic models

This project initialised spring 2007 will develop and apply quantitative models for evaluating sustainability of energy production from agriculture taking into account biomass production (e.g. growing system), technologies to convert biomass into different types of energy and recycling of residues and products. Sensitivity of model conclusions will be studied by comparing different models and systems as well as by including statistical uncertainties of input data.

The project is part of an interdisciplinary collaboration between 1) a group at the Biosystems Department with a long established expertise on the agro-ecosystem and modelling biological interactions, and a strong network with Danish and international agricultural research, and 2) a group at the Systems Analysis Division with a long established expertise on analysis of energy systems and energy technologies and a strong network with international organizations.

Ingeborg Callesen, who holds a PhD in forest ecology, is working on the project, which includes participation in the modelling activities within the EU RES2020 projects

7.3 Special purpose models

The national and regional models that are developed using the ETSAP tools normally cover the whole energy system, which is a collection of several sectors with numerous parameters and assumptions. To maintain and improve the quality of these assumptions it is important to isolate parts of the system to study the impact of the choice of specific parameter values.

Some of the tutorials developed within ETSAP also offer the possibility to go beyond the objective of learning to be used as tools for special purpose models for considering assumptions and calibration of parameters within parts of the energy system.

7.3.1 Wind power

Wind power is the topic of numerous models, often in great details concerning time resolution, geography and stochastics. However, little will be gained to develop models using the TIMES model generator in details necessary to address such issues. A different path will be to use aggregated parameters based on model studies using a model approach designed for wind. This is necessary for a model that shall be able to consider investment in wind power in competition with thermal generation. This issue has been addressed within the framework of ETSAP Annex X, but no satisfactory solution has yet been found. The issue will become even more important in the future, because wind power will become a very significant technology for electricity generation with significant implications for system operation and security.

7.3.2 Large energy consuming industries

Large energy consuming industries are not important in Denmark, but they have traditionally been the topic for many optimisation models, including NEEDS-TIMES. Some activities will be useful for completion of the Danish NEEDS-TIMES model, in particular for comparison with other national models.

7.3.3 Agriculture, forestry and biomass

Agriculture and forestry is the basis for biomass energy. This has been the topic for several modelling studies, which are also being implemented into the ETSAP tools, e.g. within the RES2020 project. However, the topic need to be studied both in further details and with the objective of creating aggregate parameters that is consistent with other sectors and, thus, more useful in models that are covering all energy sectors.

Bibliography

Balmorel Project (2001), Balmorel: A Model for Analyses of the Electricity and CHP Markets in the Baltic Sea Region. [www.balmorel.com].

Borrelli, G.; Cook, I.; Hamacher, T.; Lackner, k.; Lako, P.; Saez, R.; Tosato, G.C..; Ward, D.J. (2001) Socio-Economic Research on Fusion. Summary of EU Research 1997-2000. EFDA–RE–RE–1.

Danish Ministry of Transport and Energy (2005). Energy Strategy 2025. [www.ens.dk/graphics/Publikationer/Energipolitik_UK/Energy_Strategy_2025/pdf/Energy_strategy_2025.pdf

DEA (2005), Technology Data for Electricity and Heat Generating Plants. Danish Energy Authority, Eltra, Elkraft System. [ens.netboghandel.dk/english/PUBL.asp?page=publ&objno=250000115]

Danmarks Statistik (2002), Nationalregnskab: Kilder og metoder.

Directorate-General for Research (2005), SAPIENT – Systems Analysis for Progress and Innovation in Energy Technologies, NTUA Athens.

Directorate-General for Research (2005), SAPIENTIA – Systems Analysis for Progress and Innovation in Energy Technologies for Integrated Assessment, NTUA Athens.

Directorate-General for Research (2006) Biofuels in the European Union – A vision for 2030 and beyond, EUR 22066

EFDA (2008), An assessment of the EFDA SERF (Socio-Economic Research on Fusion) and Proposed future directions (A review of SERF 1997-2006 and recommendations for a future research agenda in FP7).EFDA Ad-Hoc Group on Socio-Economics. January 2008

Energiministeriet (1981), Energiplan 81. København. [ens.netboghandel.dk/PUBL.asp?page=publ&objno=16315603]

Energistyrelsen (1995), Teknologidata for el- og varmeproduktionsanlæg. København. [ens.netboghandel.dk/PUBL.asp?page=publ&objno=128681589].

Energistyrelsen (2005), Analyse vedrørende olie og naturgasressourcer.

Energistyrelsen (2005), Sammenfattende baggrundsrapport for Energistrategi 2025.

Energistyrelsen (2005), Basisfremskrivning af el- og fjernvarmeproduktionen 2005-2025. Teknisk baggrundsrapport til Energistrategi 2025

Energistyrelsen (2005), Scenarier for udbygning af el- og kraftvarmekapacitet. Teknisk baggrundsrapport til Energistrategi 2025

Energistyrelsen (2005) Energistatistik.

ETSAP News, Vol. 7, No. 3, September 2000. (Learning curves).

ETSAP News, Vol. 7, No. 6, October 2001 (Energy Technology Perspectives).

ETSAP News, Vol. 7, No. 7, January 2002 (The MARKAL Family of Models).

ETSAP News, Vol. 8, No. 5, June 2005. (MARKAL-NORDIC, NEEDS)

ETSAP News, Vol. 8, No. 6, July 2005. (NEEDS)

European Commission (2008), Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources, COM(2008) 19 final.

European Union, Directive 2001/80/EC of 23 October 2001 on the limitation of emissions of certain pollutants into the air from large combustion plants.

European Union, Directive 2001/77/EC of 27 September 2001on the promotion of electricity produced from renewable energy sources in the internal electricity market

European Union, Directive 2003/54/EC of 26 June 2003 concerning common rules for the internal market in electricity and repealing Directive 96/92/EC

European Union, Directive 2003/55/EC of 26 June 2003 concerning common rules for the internal market in natural gas and repealing Directive 98/30/EC.

European Union, Directive 2004/8/EC of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EEC

EUSUSTEL - European Sustainable Electricity; Comprehensive Analysis of Future European Demand and Generation of European Electricity and its Security of Supply. Final Technical Report. February 2007

Gargiulo, Maurizio (2008), Getting started with TIMES-VEDA, Draft 2.1, January 2008. (with contributions of Gary Goldstein, Amit Kanudia, Antti Lehtila, Uwe Remme, GC Tosato).
Gielen, D. (et al.) (2008). Paper prepared for the International Energy Workshop, Paris, 30 June-2 July 2008
Grohnheit, P. E. (1993), Modelling CHP within a national power system. Energy Policy, Vol. 21, No. 4, p. 418-429.
Grohnheit, P. E. (1997), Application and limitations of annual models for electricity capacity development. In: D. W. Bunn and E. R. Larsen (Eds.), Systems Modelling for Energy Policy. John. Wiley & Sons.
Grohnheit, P.E (1999), Energy policy responses to the climate change challenge: The consistency of European CHP, renewables and energy efficiency policies. (Office for Official Publications of the European Communities, Luxembourg) (Energy in Europe, Special issue, December 1999 with appended CD-ROM) [www.shared-analysis.fhg.de./; www.risoe.dtu.dk/rispubl/SYS/syspdf/ris-r-1147.pdf]
Grohnheit, P.E. (2002). Denmark: Long-term planning with different objectives. In: Climate change and power. Economic instruments for European electricity. Vrolijk, C. (ed.), (Earthscan Publications Ltd., London,) p. 108-130
Grohnheit, P.E (2007) NEEDS National report 20-02-07. [www.needs-project.org]
IEA (2006). Energy Technology Perspectives 2006
IEA (2008). Energy Technology Perspectives 2008
Kanudia, A.; van Regemorter, D. (2007) Projections of the demand of energy services. NEEDS Project note.
Krogh, T. (1998) En MARKAL modell for Danmark. Forutsetninger og resultater, IFE, Kjeller, Norway.
Larsson, T. (1995), Benefits from Electricity Trade in Northern Europe under CO2 Constraints. Energy Models for Policy and Planning. London Business School/IFORS. London, July 18-20, 1995. Published in Systems Modelling for Energy Policy, Ed. by Derek W. Bunn and Erik R. Larsen, Wiley 1997.
Larsson, T.; Grohnheit, P. E.; Unander, F. (1998) Common Action and Electricity Trade in Northern Europe. IFORS Triennial Conference. OR bridging the Theory and Practice of Decision Making, Vancouver, B.C. Canada, July 8-12, 1996. International Transactions in Operational Research. Vol. 5. No. 1
Manthey, C. (ed.) (1980), Energy technology data handbook. Vol. 1: Conversion technologies, JÜL-SPEZ--70(v.1) Applied Systems Analysis No. 18. IEA Systems Analysis Project.
Manthey, C.; Tosato, G.C. (eds.) (1980), Energy technology data handbook. Vol.2: End-use technologies. Insulation, space- and water heating systems. A technical and economic comparison, .JÜL-SPEZ--70(v.2), Applied systems analysis No. 19, IEA Energy Systems Analysis Project
Møller Andersen, F. (ed.); Werner, M.; Jensen, J.D.; Jensen, T.S.; Henriksen, G.T.; Olsen, A.; Illerup, J.B.; Nielsen, C.; Winther, M., Environmental satellite models for ADAM. (Statistics Denmark, Copenhagen, 2001).
NEEDS Project (2005). Deliverable D1.4. Draft common structure of the national country models.
NEEDS Project, Deliverable RS2a_T3.15 Interim Report on draft Pan-European Integrated Model
NEEDS Project, Deliverable RS2a_T2.7: Reference technology database
NEEDS Project (2008), Guidelines to Policy Use of NEEDS results. [www.needs-project.org/docs/Policy%20Guidelines.pdf].
Rydén, Bo (red), (2003), Nordleden. Slutrapport för etapp 2. Oktober 2003. Nordledens kansli, c/o Profu
Statistics Denmark. [www.statistikbanken.dk].
Thomas Unger, Owe Andersson, Bo Rydén, Clas-Otto Wene (2000), The NORDLEDEN Project. Final Report, March 2000. Cross-border grid-distributed energy trade and common action among the Nordic countries to facilitate CO2 reductions. Chalmers University of Technology, Göteborg, Sweden.
WILMAR (Wind Power Integration in Liberalised Electricity Markets) [www.wilmar.risoe.dk]
www.windpower.org.